THESIS ON MECHANICAL AND INSTRUMENTAL
ENGINEERING E49

Energy Planning Models Analysis and Their Adaptability for Estonian Energy Sector

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

Nadežda Dementjeva

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MASINA- JA APARAADIEHITUS E49

Energeetika planeerimise mudelite analüüs ja nende rakendatavus Eesti energiasektoris

NADEŽDA DEMENTJEVA

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If you predict what will take place in the market, it will certainly prove to be wrong. *Saying by Margus Vals.*

INTRODUCTION

Motivation of the study

Energy is an essential part of the social and economic development of any country and nation. Due to increasing awareness of the environmental impact of energy production, the goal of national energy policies is not only to guarantee a secure and cost-effective energy supply, but also to minimize the harmful side effects and, eventually, develop a sustainable energy system. Despite the increasing investments in research and development of the utilization of the renewable energy sources, the total energy production from fossil fuels is most likely going to continue its growth at a considerable rate.

Estonia is a small country where electricity production, mining and processing of oil shale form a regional economic complex with its difficulties. Estonia is the only country in Europe that has a significant oil shale mining industry and 95 % of Estonian electricity is produced by oil shale power plants. The Baltic States are facing a complex situation of breaking up the monopoly and developing a free electricity market issues in the European Union accession negotiations. Estonia has also applied for a transition period for the development of the oil shale-based energy sector.

The trend of liberalization and changes in the Estonian energy market, related to the European Union's strict technological and environmental requirements, give rise to the need to develop the modeling of new scenarios for the energy sector in Estonia by mitigating the environmental impacts of electricity production and using new, less environment-damaging technology. The easiest way to develop scenarios is to use energy planning modeling.

Modeling is one of the complicated forecasting methods. In recent years, a large number of energy planning models have been developed for energy system analysis, including demand forecasts, supply forecasts and impacts of policy shifts on the overall energy systems. Energy planning models often become useful when analyzing complex systems involve a lot of data; they help to understand the relationships between the different parameters and work out development scenarios in any country. Energy planners and researchers could develop their own models for energy planning exercises, but in practice it is not feasible for several reasons (time consuming, level of complexity, financial limitations, etc.). Instead of developing a new model, the existing ones can be used, but the key question is to decide which model should be used. Energy models are based on different fundamental approaches and concepts, and employ a range of mathematical algorithms. As a consequence, these models vary considerably and the question arises which model is the most suited for a certain purpose or situation. The different goals in energy planning are regularly contradicting each other, which makes planning a complex issue and gives rise to a multitude of compromises.

Objectives of the thesis

Objectives of the thesis are:

- analysis and evaluation of the existing energy models in the world;
- development of the selection criteria and selection of the several energy models for the analysis of the energy market in Estonia;
- practical testing of the applicability of the selected models to Estonia.

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I would like to thank my family and friends for constant support, understanding and encouragement at different stages of the present work.

I dedicate this work to my lovely daughter Darja.

List of publications

The thesis is based on the following publications, which are referred to in the text by using the Roman numerals:

I. **Dementjeva, N.,** Siirde, A. Analysis of the characteristics of the energy model and their adaptability to the Estonian energy market. Power Engineering. 2009, No.2, pp. 107-115.

II. Hlebnikov, A., **Dementjeva, N.,** Siirde, A. Optimization of the heating network in Narva district and the analysis of the competitiveness of the oil shale CHP building in Narva, Oil Shale, 2009, Vol. 26, No.3S, pp. 269-282.

III. **Dementjeva, N.,** Siirde, A. Analysis of the current Estonian energy situation and adaptability of LEAP model for Estonian energy sector. Accepted for publication in Power Engineering.

IV. **Dementjeva, N.**, Siirde, A. Analysis of the current Estonian energy situation and its modelling for developing future forecasts by using energy planning models. 6th International Symposium „Topical Problems in the Field of Electrical and Power Engineering“. Doctoral School of Energy and Geotechnology, Kuressaare, Estonia, January 12-17, 2009, pp. 77-80.

Copies of these publications are included in Appendix A.

The personal contribution of the author

The contribution of the author to the papers included in the thesis is as follows:

I. Nadežda Dementjeva is the main author of the paper. She is responsible for the literature overview, data collection, analysis and calculation. She had a major role in writing. The author has suggested the principles of the selection of the energy planning models for certain conditions.

II. Nadežda Dementjeva participated in writing the paper. The author has made the analysis of the heat supply alternatives by using two energy planning models and calculated the economical rationality of building the new units near Narva city. She had one of the major roles in writing.

III. Nadežda Dementjeva is the main author of the paper. She is responsible for the literature overview, data collection, analysis and calculation. She had a major role in writing.

IV. Nadežda Dementjeva is the main author of the paper. She is responsible for the literature overview, data collection, analysis and calculation. She had a major role in writing.

Approval of the results

The results of this work were presented at:

- The 6th International Symposium „Topical Problems in the Field of Electrical and Power Engineering“. Doctoral School of Energy and Geotechnology. Kuressaare, Estonia, January 12-17, 2009.

Scientific novelty of the thesis

The scientific novelty of the thesis is a nontrivial methodological approach to the choice of energy models for the analysis of the energy market in Estonia.

The paper presents a comprehensive study, for the first time focused in detail on the availability and accessibility of the energy models, and provides methods and criteria for the selection of the energy models for Estonian energy sector. It is also subjected to an in-depth analysis of the current practices of the selected energy models and the applicability of the selected models to the analysis of the energy market in Estonia. All this make the thesis to be significant and valuable.

ABBREVIATIONS AND SYMBOLS

AS	Joint-stock Company
PP	Power Plant
OÜ	Limited Liability Company
GNP	Gross National Product
LP	Linear Programming
min	minimum
MIP	Mixed Integer Programming
EFOM	Energy Flow Optimization Model
TIMES	The Integrated MARKAL-EFOM System
LEAP	Long-range Energy Alternatives Planning
MARKAL	MARket ALLocation
MESAP	Modular Energy System Analysis and Planning Software
MESSAGE	Model for Energy Supply Systems Analysis and General Environment
MIDAS	Multinational Integrated Demand And Supply
RETScreen	Renewable Energy Technology Screening
PlaNet	Planning Network
DESIRE	Dissemination Strategy on Electricity Balancing for Large Scale Integration of Renewable Energy
UK	United Kingdom
EU	European Union
H_2RES	Hydrogen from Renewable Energy Sources
IEA/ETSAP	Energy Technology System Analysis Project
IIASA	International Institute for Applied Systems Analysis
IAEA	International Atomic Energy Agency
CHP	Combined Heat and Power
IRR	Internal Rate of Return
NPV	Net Present Value
GDP	Gross Domestic Product
GDI	Gross Domestic Income
SMEs	Medium-Sized Enterprises
VCRs/VCPs	Videocassette Recorders/ Videocassette Players
HH	Houshold
TV	Televisor
T&D	Transmission and Distribution
CFBC	Circulating Fluidized Bed Combustion
EEK	Estonian kroon
TED	Technology and Environmental Database
REF	Reference scenario
LG	Low-growth scenario
HG	High-growth scenario

NUC	Nuclear capacity scenario
REN	Renewable energy scenario
HYB	Hybrid scenario
LHYB	Low-growth-hybrid scenario
HHYB	High-growth-hybrid scenario
RES	Reference Energy System
P	total indigenous production
I	imports
X	exports
DS	stock changes
L	losses and own consumption in the energy sector
C_f	total end-use
C_{ne}	non-energy consumption
x_1, x_2	variables, input parameters
y	output parameter
a, b	coefficients
z	the objective function
u_j, l_j, f_i, b_i	constraints
A	the constraint matrix

Unit prefixes

k	kilo, 10^3
M	Mega, 10^6
G	Giga, 10^9
T	Tera, 10^{12}
P	Peta, 10^{15}

1 ELECTRICITY SUPPLY IN ESTONIA

1.1 Estonian Power System

Estonian Power System today is the compound complex, where oil shale fired power plants, combined heat and power plants, wind turbines and hydro plants work together.

AS Narva Elektrijaamad is one of the leading producers and sellers of electricity in Estonia and the Baltic region, a competitive company in line with environmental requirements. AS Narva Elektrijaamad supplies Estonian consumers with electricity, generating about 95 % of electricity produced in Estonia, and furnishes the city of Narva with heat. The company is also engaged in sales of fly ash, which can be used in agriculture and production of construction materials. In the begining of 2008 the electric capacity of the Narva power plants was 2 002 MW, with 1 346 MW installed at the Eesti power plant and 656 MW installed at the Balti power plant. The installed thermal capacity was 84 MW and 400 MW respectively. The main achievement of late years is introduction of a new technology of oil shale combustion in the circulating fluidized bed at Unit 8 of the Eesti Power Plant and Unit 11 of the Balti Power Plant. Application of the new technology has enabled improvement of the operational efficiency as well as considerably decreased the amount of hazardous emissions.

Iru Power Plant, the biggest producer of thermal power and the third biggest producer of electrical power in Estonia, produced 1 085 GWh of thermal power and 345 GWh of electrical power in 2008. Natural gas is the fuel used, with liquid fuels providing backup. The electrical capacity of Iru Power Plant is 190 MW, and its heat capacity is 648 MW (398 MW in co-generation mode). Today the situation on the heating market of Tallinn has changed and the new competitor Väo Power Plant has been started to work from December 2008 with 50 MW of heat and 25 MW of electrical capacity. The basic heat load of 50 MW is supplied by Väo Power Plant and Iru Power Plant is using as peak energy producer for heat supplying of Tallinn.

AS Kohtla-Järve Soojus (Kohtla-Järve District Heating Network) with heat capacity 10 MW and electrical capacity 15 MW supplies heat to the towns of Jõhvi and Ahtme and sells electric power to Eesti Energia AS. The company owns the oil-shale-fired Ahtme co-generation plant operating since 1951, and the thermal power networks in the Ahtme-Jõhvi region. On July 2009 it was decided to construct the boilerhouse in Ahtme for reserve and peak loads. Accroding to international treaties current station in Ahtme can work until the end of next year, and the new, environmentally friendly, economical and reliable in operation boilerhouse will produce heat on January 2011.

Pärnu and Tartu town are supplied by Pärnu and Tartu cogeneration plants.

Power plants using renewable energy, such as Virtsu wind turbine and Linnamäe and Keila-Joa hydroelectric plants, produced 1.2 % of the annual electrical energy production in 2008. Estonia has in operation about 59 MW of wind capacity. The largest wind parks are Paldiski 18 MW, Viru-Nigula 24 MW and Rõuste 8 MW [I].

The Eesti Energia Renewable Energy main project is Narva Wind Park that will become the biggest in Estonia, providing around 1.5 % of the annual electricity production of Eesti Energia, and being able to cover the power consumption needs of a town of 15 000 inhabitants. Two wind turbines will be built with a total capacity of 150 kW on the island of Ruhnu. The turbines will be connected to the island's power system and will produce 50–75 % of the power required by island residents. Another project of Eesti Energia is co-generation plant in Viljandi County for the production of electrical energy and fertilisers from biomass and liquid pig manure. The electrical capacity of the planned co-generation plant will be about 1.7 MW and the thermal power capacity about 1.9 MW. Thermal power will be used in the production of biogas and to cover the heat requirements of the pig farm [1]. The waste incineration plant will be built in the territorium of Iru Power Plant with electrical capacity 19 MW and thermal capacity 50 MW by year 2012.

The total electricity and heat production in Estonia by energy sources in 2008 are presented in Figure 1 and 2 [2].

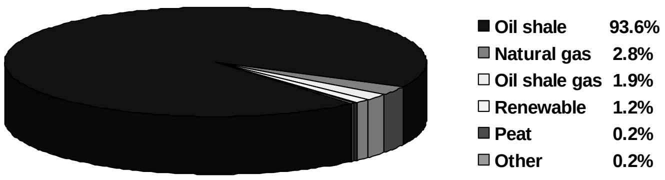

Figure 1. Total electricity generation by energy sources in 2008

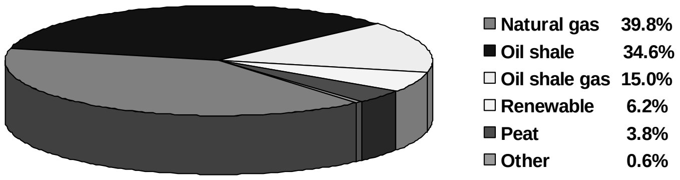

Figure 2. Total heat generation by energy sources in 2008

1.2 Estonian electricity market

The market structure has similarities to Scandinavian model with the System responsibility given to the transmission system operator. All market participants are to have an open delivery contract and balance providers need a balance agreement with system responsible party.

The Estonian electricity sector is organised around a vertically integrated utility – Eesti Energia – a state-owned enterprise that controls the generation, transmission, distribution as well as retail sales throughout almost all of the country. Eesti Energia is also involved in the construction and maintenance of energy systems. The Eesti Energia prices are under state regulation, but it is dictating conditions and connection fees to small producers for access to its network.

In 2008 the total net generation from all power plants in Estonia was 9 498 GWh, a decrease of 1 456 GWh over the year or 13 % compared to the year 2007 [2]. The total electricity consumption in Estonia was 7 836 GWh, a decrease of 97 GWh over the year or 1 % compared to the year 2007. The Estonian electricity net generation and consumption by months in 2008 is presented in Figure 3 [3].

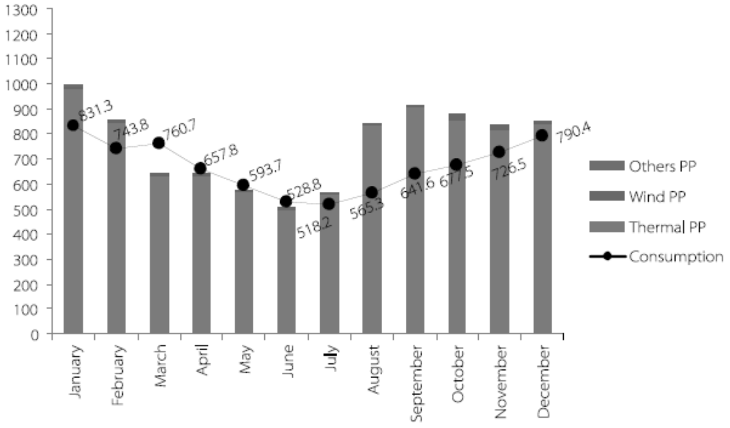

Figure 3. Estonian electricity net generation and consumption by months in 2008

According to the European Union requirements the Estonian electricity market must be opened on 35 % by the end of 2008 and fully opened by the year 2013. Liberalization of electricity market means opening of electricity production and sales for competition when the transmission and distribution remain natural monopolies. Today Estonian electricity market has been open for eligible customers whose annual consumption exceeds 40 GWh since 1999. These consumers have a right to purchase electricity from any producer or seller in the market and an obligation to pay for network services. At present there are 13 eligible costumers in the system, they consume about 16 % of energy in Estonia. Non-eligible customers can purchase their electricity from the grid company they are physically connected to or from the seller named by that grid company. Grid companies and sellers selling energy to non-eligible customers can purchase that energy from power plants using oil-shale mines in Estonia as the primary energy source or from small producers with capacities less than 10 MW.

Liberalization of electricity market or opening of electricity production and sales for competition will raise system's efficiency and quality of services in Estonia, but considering the small size of Estonian electricity market, the complication of power system control, shortage of generation capacity, costs of operating the market, volatile prices and possible lowering of supply security and reliability due to insufficient investments in the whole region can easily surpass the expected positive effect of liberalization [4].

Since March 2009 Eesti Energia's electricity weighted average price limit is 509 kr/ MWh or 32.5 €/MWh. In addition to domestic electricity sales Eesti Energia exports electricity via Nordic energy exchange Nord Pool to Finland. Electricity export price is determined by Nord Pool Finland regional price level. Additionally the Eesti Energia Group exports electricity to the other Baltic States [5].

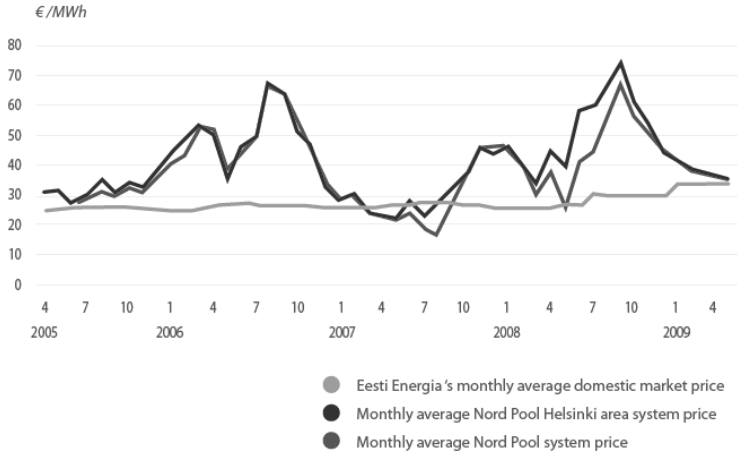

Figure 4. Eesti Energia's average domestic market price by months 2005-2009

The strategic objective of Estonian electricity sector development plan until 2020 is to assure the optimal functioning and development of Estonian power system in the market economy conditions and to assure in the long-term outlook the proper supply of electricity to the consumers at lowest price possible, at the same time implementing all reliability and environmental conditions. The main engagements and figures concerning to energy sector development by year 2020 is followed [6]:

- diversification of energy sources used in the generation sector, including construction of the Estonian nuclear power plant by 2020 and decreasing the dependency on oil-shale generation;
- by 2010, renewable electricity will form 5.1 % of gross consumption;

- by 2020, electricity produced in combined heat and power production stations will account for 20 % of gross consumption;
- to open Estonian electricity market for 35 % in 2009 and for all consumers in 2013;
- the limitation of energy consumption;
- preconditions will be established for connecting with the energy systems of the Nordic and Central European countries, including the new interconnection Estlink 2 between Estonia and Finland.

After year 2015 about 70 % of available installed net generation capacity of existing oil shale based units will be shut down. In operation will be two new fluidized bed boilers in the Narva Power plants, the second generation unit in Iru Power plant and small power plants. The Estlink cable between Finland and Estonia, commissioned right at the end of 2006, increased the opportunities for power imports and export from and to Estonia.

The major investments in electricity production will be:

- Peat and biomass CHP-s with gross capacity of 100 MW in 2010-2015
- Wind turbines with gross capacity of 618 MW by the year 2015
- 1st oil shale CFBC unit with gross capacity of 270 MW in 2015
- 2nd oil shale CFBC unit with gross capacity of 270 MW in 2016
- Natural gas combined cycle plant with gross capacity of 100 MW in 2012
- Nuclear plant with gross capacity of 600 MW in 2020.

The electricity supply and demand forecast in Estonia are presented in Figure 5 [7].

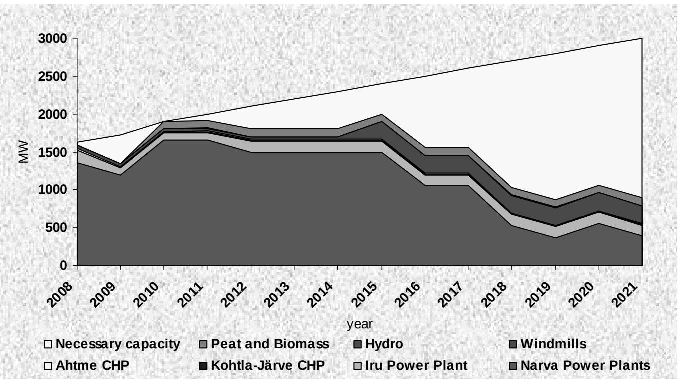

Figure 5. Electricity supply and demand forecast.

1.3 Electricity transmission and distribution

Pursuant to the Electricity Market Act, Estonia may have only one transmission system operator. The Energy Market Inspectorate issued the corresponding license to Elering OÜ which is a national grid company in the electricity market.

The task of electricity distribution is to transport electricity from the nearest transmission grid connection to consumers by using an electrical network at a voltage level of 0.4–35 kV, known as the distribution network, and then decreasing the voltage to a level suitable for consumers.

This is handled by distribution network companies, of which there are 41 in Estonia. The largest are OÜ Jaotusvõrk, OÜ VKG Elektrivõrgud and Fortum Elekter AS. Suppliers buy electricity from producers, and the electricity transport service (the network service) from distribution networks.

The Estonian energy system is interconnected with the Russian and Latvian energy systems and as from the end of year 2006 a connection has been established with the Finnish energy system through an underwater cable Estlink. Within the interconnected systems (Estonian, Latvian, Lithuanian, Belarussian and Russian electricity systems) the faults of one system have an instant effect on the other's performance in system management, technology, environmental protection and other fields [3].

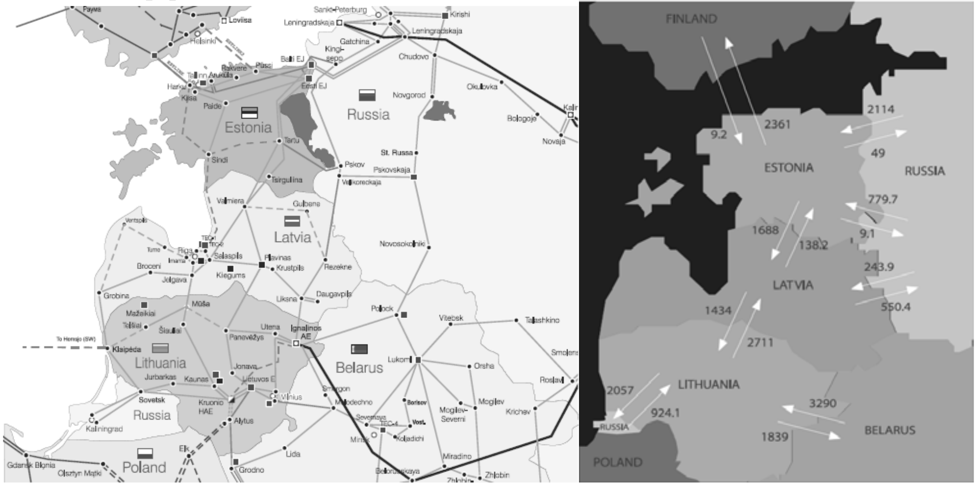

Figure 6. Baltic interconnected power system in 2008

The interconnected systems also enable electricity trade and the possibility to obtain the necessary ancillary services (i.e. frequency control, managing power reserves etc.) to maintain system reliability with a favorable price.

1.4 Environmental impact

The environmental impact of the energy industry is among the largest of any industrial sector, and limiting that impact is a major factor in decision-making in the industry. The environmental policy in Estonia is, to a very large extent, based on the environmental policy of the European Union. Estonia applies the following internationally acknowledged environmental principles: principle of prevention; "polluter pays" principle; principle of strategic integration (including environmental aspects in the development strategies in all spheres of activities and the economy); and precautionary principle. Estonian environmental legislation is based on two main framework laws: the Act related to the Protection of Nature in Estonia (1990) and the Act on Sustainable Development (1995). Estonian environmental policy is generally in accordance with European Union policy. The

Act related to Sustainable Development, adopted in February 1995, lays down the general principles of further development. Estonia's nature conservation and environmental protection goals should be reached, regardless of integration with the EU. The transposition of EU environmental legislation into Estonia's national environmental legislation can significantly accelerate this process. As Estonia has joined the most important international conventions in the field of nature conservation and environmental protection, which, in most cases, are of the same strictness as EU norms and standards, it has fair prospects for a relatively smooth approximation process [1].

Estonia's electricity production is mostly based on oil shale, which is rather carbon dioxide rich. According to national annual allowance plans for greenhouse gas emissions approved by the European Commission, the government of Estonia allocated to Eesti Energia Group companies a total of 9.2 million tonnes of greenhouse gas emissions credits for the second trading period of 2008-2012, which is about 40 % less than for the first trading period. The current size of the allowance allocated to Eesti Energia means it will be necessary to buy additional credits in order to meet domestic electricity demand and generate electricity for export [5].

Due to the nature of oil shale ash, the filters to be installed in the Narva Elektrijaamad do not use lime or any other chemical to bind sulphur, as the level of CaO in the oil shale ash is enough to lower the SO_2 content of the smoke to 400 mg/nm^3 or less. According to EU directive the amount of sulphur and nitrogen compounds in the emissions must remain below 200 mg/Nm3 and concentration of fly ash in the emissions must not exceed 30 mg/Nm3. The restrictions will also force to act earlier than this, as regulations state that from 2012 the SO_2 emissions from Narva Elektrijaamad may not exceed 25 000 tonnes a year. Various methods of lowering the SO_2 level have been tested, but none has produced satisfactory results, and research continues. Ahtme power plant, which also runs on oil shale as fuel and where the equipment is significantly older than that at Narva Elektrijaamad, will be closed at the end of 2010.

Natural gas is the cleanest fossil fuel, but additional steps to lower pollution from NO_x emissions even further have been taken at Iru Power Plant, which runs on natural gas. By using more efficient furnaces with lower NO_x and optimising the location of the furnaces, the Iru plant was able to achieve the required level of emissions in smoke of 200 mg/nm^3.

Wind energy is seen by some as a danger to birds and bats, and wind turbines also have an aesthetic effect – such installations may not suit every landscape – and create low-frequency noise and vibration. Environmental effects from hydro plants involve ground problems arising from the blocking and swelling of bodies of water, and the hindrance to the movement of fishes, especially rare species, to their spawning areas. Today there have not been built new dams, the Estonian existing old hydro plants are restored and renovated in line with all requirements [1].

2 ENERGY SYSTEM MODELS

Modeling is one of complicated forecasting methods. Mathematical modeling means the describtion of economical vision by using the mathematical formulas, equations and inequalities.

Models become often useful when analysing complex systems with large amount of data. Through models, various linkages and effects between different phenomena can be mathematically described and data can be processed and updated practically. Models may, for example, help to understand correlation between different parameters and reveal relationships that would otherwise remain unrecognised. Sometimes a model might be needed only to understand and interpret existing data. Scenarios and sensitivity analyses are frequently used to estimate the influence of varying conditions on the studied system.

Real systems are normally far too complicated to be perfectly represented in a model, and consequently many simplifications have to be done. These simplifications, uncertainties and possible mistakes regarding model parameters, nature's chaotic behaviour and unforeseen phenomena among many other things tend to make model results untrustworthy. Thus, one should have a good understanding about the model and the data used in modelling before employing the results. Many times the experience and knowledge of the system gained by building a model, as well as the questions that arise during modelling process, become more valuable than the results produced by the model. Models can be considered rather as a way of gaining insight of complex systems than providing direct answers for decision making.

Energy models were first developed in the 1970s because of the increasing availability and development of the computers and the increasing environmental awareness. Most of the energy models were built and used in industrialised countries, so that the main assumptions about energy systems were mainly based on the experience from these countries. Energy models are based on different fundamental approaches and concepts, and employ a range of mathematical algorithms. As a consequence, these models vary considerably and the question arises which model is most suited for a certain purpose or situation.

In order to decide which model is better to use, it is important to explain the model characteristics, structures, data and modelling methods. The ways of classification is given in this work and the basic distinctions of the types of models such as econometric, macro-economic, economic equilibrium, optimization, simulation, spreadsheet/toolbox and backcasting are described. In practice, it is not feasible to develop own models for energy planning exercises by energy planners and researchers, more effective to use existing models, but the key question is to decide which model should be used. A classification scheme can provide insight in the differences and similarities between energy models and thus helps the selection of the proper energy models.

2.1 Model classifications

Models are built for various purposes and consequently have different characteristics and applications. The nine ways of classification are presented in this work [8]:

1. General and Specific Purposes of Energy Models
2. The Model Structure: Internal Assumptions & External Assumptions
3. The Analytical Approach: Top-Down vs. Bottom-Up
4. The Underlying Methodology
5. The Mathematical Approach
6. Geographical Coverage: Global, Regional, National, Local or Project
7. Sectoral Coverage
8. The Time Horizon: Short, Medium and Long Term
9. Data Requirements

Such classification of energy models is helpful for understanding their need, their roles and their specificity in relation to the studies under consideration.

2.1.1 General and Specific Purposes of Energy Models

Models are usually developed to address specific questions and therefore suitable only for the purpose they were designed for. Incorrect application of a model may result in significant misinterpretations which cannot be ascribed to poor model functioning but, are the responsibility of the model users. There are made a distinction between general purposes for energy modeling (forecasting, exploring, backcasting) and more specific purposes such as demand/ supply analysis, impact analysis, or appraisal.

2.1.1.1 General Purposes

General purposes are the purposes that reflect how the future is addressed in the model. There are three general purposes of energy models:

To predict or forecast the future

Because prediction is based on extrapolation of trends found in historical data, forecasting models are usually only applied for analyzing relatively short-term impacts of actions. A prerequisite for such an extrapolation is that critical underlying development parameters (e.g., elasticities) remain constant.

This approach requires an endogenous representation of economic behavior and general growth patterns and is most found in short-term, econometrically driven economic models.

To explore the future (scenario analysis)

Exploring the future is done by scenario analysis, in which a limited number of “intervention” scenarios are compared with a “business as usual” reference scenario. The alternative intervention scenarios are only relevant in the context of the reference scenario and rely on assumptions rather than parameters extracted from past behavior. Generally, assumptions must be made about economic behavior, physical resource needs, technical progress, and economic or population growth. Economic behavior is usually represented or simulated either by a “least cost optimization" (utility) approach or in terms of technology adoption processes. Sensitivity analyses are crucial to provide information on the effects of changes in the assumptions. The scenario analysis approach can be used in the so-called "bottom-up" models as well as the "top-down" models.

To look back from the future to the present ("backcasting")

The purpose of backcasting models is to construct visions of desired futures by interviewing experts in the fields and subsequently look at what needs to be changed to accomplish such futures. This approach is often used in alternative energy studies and can also be seen as a separate methodology. However, it is possible to use this methodology as an analytical tool for assessing the long run (economic) consistency of the alternatives. This way, the "bottom-up" models can be linked with the "top-down" models.

2.1.1.2 Specific Purposes

More specific or concrete purposes of energy models are the aspects on which the models focus, such as energy demand, energy supply, impacts, or appraisal.

I. Energy Demand Models

Demand models focus on either the entire economy or a certain sector and regard demand as a function of changes in population, income, and energy prices. Demand planning consists of programms elaboration to manage the demand and provide the work of energy system with minimal costs. Energy demand models are those, which are basically used for energy demand forecasting.

II. Energy Supply Models

Supply models focus mainly on the technical aspects concerning energy systems and whether supply can meet a given demand, but may include financial aspects using a least-cost approach. Supply planning consists of capacity of power plants, transmision and distribution planning to provide minimal costs and satisfy the customers load needs. Energy supply models are those, which are mainly used for energy supply forecasting.

III. Energy System Models

Energy system models are used for overall energy system analysis including demand, supply and balance.

IV. Impact Models

Impacts can be caused by using certain energy systems or enact certain policy measures. Impacts may include changes in the financial/economic situation, changes in the social situation (distribution of wealth, employment), or changes in health and the environment (emissions, solid or liquid waste, biodiversity). Impact models assess the consequences of selecting certain options.

V. Appraisal Models

If there are several options they need to be compared and appraised in order to select the most suited option. Even if there seems to be only one option to be appraised there will always be the other option of not selecting the option which has consequences as well. The consequences or impacts of each option are compared and appraised according to one or more preset criteria of which efficiency (technical as well as cost) is the most commonly used.

Recent models generally have an integrated approach in the sense that they combine several specific purposes. Demand-supply matching models and impact-appraisal models are common examples of integrated models, but an integrated approach is also required to study energyeconomy-environmental interactions. Also, almost all models include some indication of costs as a means for appraisal. Some models are constructed as a modular package, which enables the user to select only those modules or submodels that are relevant.

Another aspect concerning the purpose is what form of energy the model addresses. Not all models include all forms. In fact, there exist many models which focus on electricity exclusively. On the other hand, some models that address "energy" as a whole, can not differentiate between different forms of energy and thus do not deal with the fact that not all energy forms are suited for certain purposes (e.g., there is no use in supplying more heat to the end-users if people want to use more electrical appliances) [8].

2.1.2 The Model Structure: Internal and External Assumptions

Besides the purpose of models, the models can also be distinguished according to their structure, more specific the assumptions on which the structure is based. For each type of model, a decision has to be made on which assumptions will be embedded in the model structure (the implicit or internal assumptions) and which are left to be determined by the user (i.e., external or input assumptions). There are distinguished four independent dimensions with which the structure of models can be characterized:

I. The degree of endogenization

Endogenization means the attempt to incorporate all parameters within the model equations so as to minimize the number of exogenous parameters. Predictive models have endogenized behavior, while exploring or backcasting models use external (or input) assumptions about behavior which make them more suited to simulate the effects of changes in historical patterns.

II. The extent of the description of the non-energy sector components of the economy

Non-energy sector components include investment, trade, consumption of non-energy goods and services, income distribution, and more. The more detailed the model's description of the non-energy sectors, the more suitable the model is for analyzing the extent to which energy policy measures affect the entire economy.

III. The extent of the description of energy end-uses

The more detailed the model's description of energy end-uses, the more suitable the model is for analyzing the technological potential for energy efficiency.

IV. The extent of the description of energy supply technologies

The technological potential for fuel substitution and new supply technologies can best be analyzed if the model allows for a detailed description of technologies. Most models with an economic background represent technology only in a highly aggregated manner, treating it as a black box. This makes them less suited for analyzing different supply technologies.

For each of the four dimensions there is a range from “more” to “less” and each energy model can be ranked somewhere on that range. As far as parameter values are not assumed within the energy model, the model users themselves will have to make external assumptions about these parameters. External assumptions often include assumptions about:

I. Population growth

Other things being equal, population growth increases energy demand.

II. Economic growth

Economic growth generally causes an increase in activities for which energy is needed (this does not have to imply, however, that energy demand increases because energy efficiency might increase at the same time). Another consequence of economic growth is that it reduces the economic lifetime of energy-using equipment.

III. Energy demand

Energy demand is influenced by structural changes in an economy because different sectors have different energy intensities. Furthermore, the choice of technology and the associated energy efficiency affect the demand for energy.

IV. Energy supply

Energy supply is determined by the short-term availability of alternative resource supplies as well as by backstop technologies which give an indication of the cost at which an infinite alternative supply of energy becomes available (and thus provide information on the maximum cost of a policy).

V. Price and income elasticities of energy demand

Elasticities measure the relative change in energy demand, given relative changes in energy prices and in incomes. Higher elasticities imply larger changes in energy use.

VI. Existing tax system and tax recycling

Taxes can have large impacts on the total costs of energy systems.

There has to be always at least one external parameter, anyway if all the parameters of a model have to be determined exogenously, the model would be no more than a computational device. In practice, energy models will be placed somewhere between these two extremes [8].

2.1.3 The Analytical Approach: Top-Down vs. Bottom-Up

By the analytical approach models can be divided as top-down, bottom-up and hybrid. The distinction between top-down and bottom-up models is particularly interesting because they tend to produce opposite outcomes for the same problem.

The differences in outcomes of top-down and bottom-up models stem from the distinct manners in which these two types of models treat the adoption of technologies, the decision-making behavior of economic agents, and how markets and economic institutions actually operate over a given period of time.

Economics regards technology as a set of techniques by which inputs such as capital, labor, and energy can be transferred into useful outputs. The “best” or most optimal techniques (defined by efficient markets) determine the so-called economic “production frontier” (see Figure 7) which can be constructed by observing actual behavior. No investments are possible beyond this frontier. However, it is possible to move the frontier towards the origin by means of technological progress.

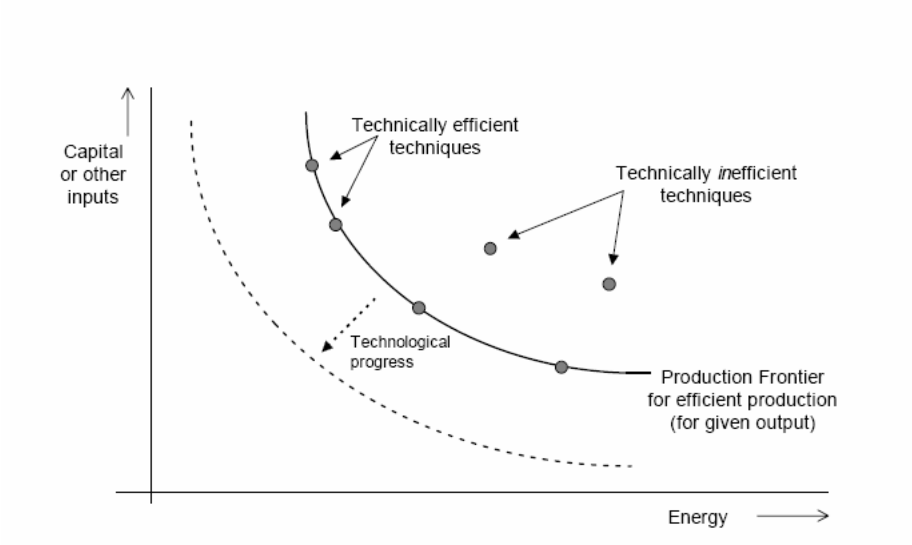

Figure 7. The production frontier from an economical perspective

A purely economic model has no explicit representation of technologies, but uses elasticities which implicitly reflect the technologies.

Technological change in most economic models is represented by the “autonomous energy efficiency index” and the “elasticity of substitution” between the aggregate inputs to households and firms. Stated otherwise, technology is treated as a black box, which makes it difficult to convert detailed technological projections into the production functions of these models.

Engineering studies, on the other hand, are independent of observed market behavior. They describe the techniques, the performances, and the direct costs of all technological options in order to identify possibilities for improvement. In practice, the technological potential differs from the “best” technologies that represent the economic production frontier in economic models. The difference arises due the fact that the engineering approach tends to ignore existing constraints, while the economic production frontier is based on market behavior. These constraints include hidden costs, costs of implementation measures, market imperfections, macro-economic relationships (multiplier effects, price effects), and macro-economic indicators (GNP, employment). Market behavior can be regarded as a result of the existence of these constraints. Therefore, models which are based on data derived from actual behavior are believed to automatically include existing constraints.

Another characteristic of top-down models is that they use aggregated data to examine interactions between the energy sector and other sectors of the economy, and to examine the overall macro-economic performance of the economy. This is done by endogenizing behavioral relationships as much as possible. Past behavior can then be extrapolated into the future, which makes top-down models suitable for predictive purposes on the short term.

In contrast, bottom-up models usually focus on the energy sector exclusively, and use highly disaggregated data to describe energy end-uses and technological options in detail. Bottom-up models can be further subdivided into descriptive and prescriptive models.

Descriptive models try to provide a practical estimate of the technology mix that would result from actual decisions, based on factors such as complex preferences, intangible costs, capital constraints, attitudes to risk, uncertainty, and market barriers. Prescriptive studies, on the other hand, provide an estimate for the technological potential by examining the effects of acquiring only the most efficient existing technologies (or of minimizing explicit costs for a given service at a system level). As a consequence, descriptive models are typically less optimistic than prescriptive studies. In a sense, the purpose of descriptive models tends towards prediction and it can be seen as an attempt to bridge the gap between the engineering paradigm and the economic paradigm, while the purpose of prescriptive models tends more towards exploration.

Top-down and bottom-up models can be combined in a hybrid approach, depending on purpose, data requirements and desired output. For instance, many top-down models now also allow for simulations. This implies that different outcomes must then be ascribed to differences in external or input assumptions rather than differences in model structure [8].

Top-down models are most useful for studying broad macroeconomic and fiscal policies for mitigation such as carbon or other environmental taxes. Top-down models externalise major structural changes such as lifestyles, urbanisation and technological changes. The strengths of the top-down approach are its consistency, its links to historic references and economic frameworks, equilibrating prices and quantities and its data availability.

Bottom-up models are most useful for studying options that have specific sectoral and technological implications. A bottom-up approach can be useful, mainly because the model is independent of market behaviour and production frontiers and because technologies are explicitly modelled. The weaknesses of bottom-up models are that main drivers remain exogenous such as demand, technology change and resources.

The hybrid approach leads to flexible models, because it combines the advantages of top-down and bottom-up models. Both top-down and bottom-up models can be useful for certain purposes of future forecasts, but the most energy planning models are focused on bottom-up or hybrid approaches because of their flexibility [8].

The different aspects associated with top-down and bottom-up models are summarized in Table 1.

Table 1. Characteristics of top-down models and bottom-up models

Top-Down Models	Bottom-Up Models
use an “economic approach”	use an “engineering approach”
give pessimistic estimates on “best” performance	give optimistic estimates on “best” performance
can not explicitly represent technologies	allow for detailed description of technologies
reflect available technologies adopted by the market	reflect technical potential
the “most efficient” technologies are given by the production frontier (which is set by market behavior)	efficient technologies can lie beyond the economic production frontier suggested by market behavior
use aggregated data for predicting purposes	use disaggregated data for exploring purposes
are based on observed market behavior	are independent of observed market behavior
disregard the technically most efficient technologies available, thus underestimate potential for efficiency improvements	disregard market thresholds (hidden costs and other constraints), thus overestimate the potential for efficiency improvements
determine energy demand through aggregate economic indices (GNP, price elasticities), but vary in addressing energy supply	represent supply technologies in detail using disaggregated data, but vary in addressing energy consumption
endogenize behavioral relationships	assess costs of technological options directly
assumes there are no discontinuities in historical trends	assumes interactions between energy sector and other sectors is negligible

2.1.4 The Underlying Methodology

Concerning the underlying methodology there are seven types of commonly used methodologies:

1. econometric,
2. macro-economic,
3. economic equilibrium,
4. optimization,
5. simulation,
6. spreadsheet,
7. backcasting.

In practice, the distinction is not always clear, the literature make a distinction between simulation, optimization, and spreadsheet methods usually only when referring to bottom-up models, while recent economic top-down models use optimization and simulation techniques as well. On the other hand, econometric, macro-economic, and economic equilibrium methods are generally only applied in top-down models, although there are exceptions here also.

I. Econometric Models

Econometric methodologies are methodologies that apply statistical methods to extrapolate past market behavior into the future. Nowadays econometric methodologies are mainly used as parts of macro-economic models. They rely on aggregated data that have been measured in the past to predict the short- or medium-term future in terms of labor, capital, or other inputs. They are also frequently used to analyze energy-economy interactions. So, generally, the purpose of econometric models is to predict the future as accurately as possible using measured parameters.

A disadvantage of this methodology is that it does not represent specific technologies at all and could not be use for long-term planning. Also, variables are based on past behavior and trend analysis also extrapolates past trends of energy-economic activity. However, trend analysis is not suited for policy analysis partly due to the fact that it requires highly aggregated data (to reduce fluctuations in behavior over time) and does not allow for energy-economy feedbacks. It cannot capture structural change and does not explain determinants of energy demand.

II. Macro-Economic Models

The macro-economic methodology focuses on the entire economy of a society and on the interaction between the sectors and well known as input-output models. It is often applied in energy demand analysis when taken from a neo-Keynesian perspective (i.e., output is demand determined). Input-output tables are used to describe transactions among economic sectors and assist in analysis of energy-economy interactions. The Input-output models are often developed for exploring purposes, using assumed parameter and scenarios which do not necessarily have to reflect reality.

Similar to the econometric methodology, the macro-economic methodology has the disadvantage that it does not represent specific technologies and long-term expectations are not taken into account.

III. Economic Equilibrium Models

Where econometric and macro-economic methods are mainly applied to study the short or medium term effects, economic equilibrium methodologies focus on the medium to long term. They are used to study the energy sector as part of the overall economy and focus on interrelations between the energy sector and the rest of the economy. Economic equilibrium models are sometimes also referred to as resource allocation models. Some energy-economic models consider energy price equilibrium while balancing supply and demand. Price equilibrium energy-economic models are basically used for policy analysis, rather than for energy supply and demand forecasts. Price equilibrium energy-economic models can further be divided into two categories:

- partial equilibrium models,
- general equilibrium models.

Partial equilibrium models only focus on equilibria in parts of the economy, such as the equilibrium between energy demand and supply.

General equilibrium models consider simultaneously all the markets in an economy, allowing for feedback effects between individual markets.

Economic equilibrium methodologies rely on (neo-classical) perfect market equilibrium assumptions; output is determined by supply and markets “clear” (there exists no structural unemployment). The disadvantage of these models is that they do not provide adequate information on the time path towards the new equilibrium, implying that transition costs are understated.

IV. Optimization Models

Optimization methodologies are used to optimize energy investment decisions endogenously (i.e., the results are directly determined by the input). The outcome represents the best solution for given variables while meeting the given constraints. Optimization is often used by utilities or municipalities to derive their optimal investment strategies. Furthermore, in national energy planning, it is used for analyzing the future of an energy system. Underlying assumption of optimization methodologies is that all acting agents behave optimal under given constraints. Disadvantages are that optimization models require a relatively high level of mathematical knowledge and that the included processes must be analytically defined. Optimization models often use linear programming techniques.

V. Simulation Models

Simulation models are descriptive models based on a logical representation of a system, and they are aimed at reproducing a simplified operation of this system. Simulation models are a “what if” tool, they calculate what would happen under given assumptions of consumption forecasts and policies. Such models, however, allow the users to explore different hypotheses via scenarios, and typically capture the area of interest at a macro-economic level. These models are used to investigate technologically oriented measures where macro-economic interactions i.e. price effects are less important. Simulation models are especially helpful in cases where it is impossible or extremely costly to do experiments on the system itself. They are often used in scenario analysis.

A particular type of simulation model is achieved through accounting models. These models set up an accounting balance for the flow of energy through an economy for each time period usually one year. They are like assets have to equal liabilities in a financial balance sheet, supply needs to equal consumption in an energy balance. It can be explained mathematically by equation 1.1:

$$P + I - X - DS = L + C_f + C_{ne} \qquad (1)$$

where P - total indigenous production,

I - imports,

X - exports,
DS - stock changes,
L - losses and own consumption in the energy sector,
C_f - total end-use,
C_{ne} - non-energy consumption.

VI. Spreadsheet Models (Tool Boxes)

In the literature the spreadsheet methodology is often mentioned as a separate (bottom-up) methodology. Although the models all make use of spreadsheets (as the term suggests), this term may cause some confusion because other methodologies also frequently use spreadsheet programs as a basis. Spreadsheet models are as "tool boxes" which often include a reference model that can easily be modified according to individual needs.

VII. Backcasting Models

The backcasting methodology is used to construct visions of desired futures by interviewing experts in the fields and subsequently by looking at which trends are required or need to be broken to accomplish such futures. This approach is often used in alternative energy studies [9].

2.1.5 The Mathematical Approach

At the level of concrete models, a further distinction can be made regarding the mathematical approach or procedures applied in the models. Commonly applied techniques include linear programming, mixed integer programming and dynamic programming. The combinations of techniques within a model are also possible. Mathematical techniques that only recently have been applied to energy planning, such as multi-criteria techniques and fuzzy logic, are not addressed here.

I. Linear Programming (LP)

Linear programming is a practical technique for finding the arrangement of activities which maximizes or minimizes a defined criterion, subject to the operative constraints. All relationships are expressed in fully linearized terms. Linear programming can be used, for instance, to find the most profitable set of outputs that can be produced with given type input and given output prices. The technique can deal only with situations where activities can be expressed in the form of linear equalities or inequalities, and where the criterion is also linear. That is, if x_1 and x_2 are inputs and y is the output, the technique is only applicable if their relationship is of the form:

$$y \leq ax_1 + bx_2 \qquad (2)$$

LP is a relatively simple technique which gives quick results and demands little mathematical knowledge of the user.

Disadvantages are that all coefficients must be constant and that LP results in choosing the cheapest resource up to its limits before any other alternative is used at the same time for the same item. Also, LP models can be very sensitive to input parameter variations. This technique is used for almost all optimization models, and applied in national energy planning as well as technology related long-term energy research.

Linear optimization is aimed to find the optimal value of a linear function of a certain number of variables (usually labeled $x_1, x_2 \ldots x_n$). An optimization problem in an n-dimensional variable $x = (x_1, \ldots x_n)^T$ can be generally written as [9]:

$$\min\left[z = z(x_1, \ldots x_n)\right] \qquad (3)$$

subject to

$$f_i(x) \geq b_i \ , \qquad i = 1, \ldots, m$$

$$u_j \geq x_j \geq l_j \qquad j = 1, \ldots, n$$

z is called the objective function. In the case of energy system z might be total costs, emissions of a specific substance or the amount of employment created by the system, for example, or a combination of them,

uj, *lj*, *fi* and *bi* are used to set constraints that define the space of allowed or feasible solutions.

These constraints may include restricted availability of resources or maximum allowable emission levels. If both *z* and *f* are linear in *x*, i.e.

$$z = cx = \sum_{j=1}^{n} c_j x_j \qquad (4)$$

$$f = Ax \Leftrightarrow \forall i : f_i = \sum_{j=1}^{n} a_{ij} x_j \qquad (5)$$

where *A* is the constraint matrix and all *lj* are non-negative $l \geq 0$.

II. Mixed Integer Programming (MIP)

Mixed Integer Programming (MIP) is actually an extension of Linear Programming, which allows for greater detail in formulating technical properties and relations in modeling energy systems. Decisions such as Yes/No or (0/1) are admitted as well as nonconvex relations for discrete decision problems. MIP can be used when addressing questions such as whether or not to include a particular energy conversion plant in a system. By using MIP, variables that cannot reasonably assume any arbitrary (e.g., small) value – such as unit sizes of power plants– can be properly reflected in an otherwise linear model.

III. Dynamic Programming

Dynamic programming is a method used to find an optimal growth path. The solution of the original problem is obtained by dividing the original problem into simple subproblems for which optimal solutions are calculated. Consequently, the original problem is than optimally solved using the optimal solutions of the subproblems [8].

2.1.6 Geographical Coverage

The geographical coverage reflects the level at which the analysis takes place, which is an important factor in determining the structure of models. The global models describe the world economy or situation, the regional level frequently refers to international regions such as Europe, the Latin American Countries, South-East Asia, etc., although the literature uses the term “regional” or “local” in some cases to refer to regions within a country. National models treat world market conditions as exogenous, but encompass all major sectors within a country simultaneously, addressing feedbacks and interrelationships between the sectors. Examples of national models are econometric models for the short term and general equilibrium models for the long term. The local level is subnational, referring to regions within a country. The project level is a somewhat special case. It usually refers to a subnational level focusing at a particular site. However, the project level can also encompass a project on a national or even international scale, although specific “project models” generally do not focus on these large scale projects.

The comprehensiveness of models focusing on the global, regional, or national level generally requires highly aggregated data and models focusing on one of these levels often include all major sectors and macro-economic linkages between those sectors, implying a considerable simplification of the energy sector. Local and project models, on the other hand, usually require a bottom-up approach using disaggregated data [8].

2.1.7 Sectoral Coverage

A model can be focused on only one sector or include more sectors. How the economy is divided into certain sectors is crucial for the analysis. Multi-sectoral models can be used at the international, national, as well as subnational level and focus on the interactions between these sectors. Single-sectoral models only provide information on a particular sector and do not take into account the macro-economic linkages of that sector with the rest of the economy. The rest of the economy is represented in a highly simplified way. Nearly all bottom-up models are sectoral, but not all sectoral models use bottom-up methodologies. For instance, top-down partial equilibrium models focus on the long term growth path of a distinct sector [8].

2.1.8 The Time Horizon: Short, Medium, and Long Term

Based on the time horizon considered for the planning exercise, energy models can also be classified as:

- Short-term models
- Medium-term models
- Long-term models.

The time horizon is important because different economic, social and environmental processes are important at different time scales. Thus, the time scale determines the structure and objectives of the energy models.

It is difficult to separate boundaries for these types of models [8]:

- econometric or input-output models are normally short-term in nature (less than 5 years),
- energy demand, supply or energy system models are medium to long term models (15 to 25 years),

- global/regional models are the example of long-term models (30 to 100 years).

2.1.9 Data Requirements

Models require certain types of data. For instance, most models will require data of a quantitative, cardinal type, some even require aspects to be expressed in monetary units. However, sometimes data are not available or unreliable (for instance in developing countries), in which case it might be important that the energy model can handle qualitative or ordinal data as well. Furthermore, data may be aggregated or disaggregated. Long-term global and national models will necessarily need highly aggregated data with little technological detail. Great detail in representing energy supply and consumption is only possible in models that are specific for the energy sector [8].

2.2 Basic structure of energy system models

2.2.1 Reference energy system

The structure of a model is often illustrated with a reference energy system (RES), which is a network depicting flows of commodities through various processes. This network includes all energy carriers involved with primary supplies (e.g., mining, petroleum extraction, etc.), conversion and processing (e.g., power plants, refineries, etc.), and end-use demand for energy services (e.g., boilers, automobiles, residential space conditioning, etc.). The demand for energy services may be disaggregated by sector (i.e., residential, manufacturing, transportation, and commercial) and by specific functions within a sector (e.g., residential air conditioning, heating, lighting, hot water, etc.). The building blocks depicted in Figure 8 represent the simplified Reference Energy System (RES) [10].

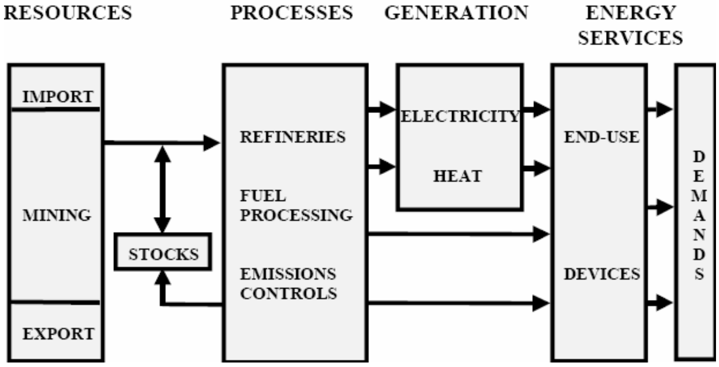

Figure 8. Reference Energy System (RES)

The RES may be used to depict an energy system from municipal or regional level to national and international energy supply. Individual plants are not modelled separately, but similar plants are aggregated into processes that represent a whole technology type. In addition to existing technologies, the RES usually contains a variety of alternatives and options of technologies that are not available today, but that can be envisaged to be utilised in the future.

2.3 The main characteristics and comparison of models

As described above there are several types of model based on different fundamental approaches and concepts.

Table 2 summarizes the main characteristics of main energy modelling approaches, including macro-economic, energy equilibrium, optimization, simulation and spreadsheet models [12].

Macro-economic models are less useful, because they extrapolate past market behaviour into the future, does not represent specific technologies and no long term planning possibilities. Economic equilibrium models are insufficient, because Estonian market economic is relatively new and changes in structure and conditions of economy are not fully formed.

The optimisation models can be useful for Estonia; they used to optimise energy investment decisions by finding best solutions. The assumption of perfect markets and optimal consumer behaviour is suitable for Estonia, because the large part of the population in Estonia consists of inhabitants who reflect consumer behaviour, have the access to modern energy, and the economy is market-based.

Another option is simulation models are mostly bottom-up or hybrid descriptive models that aim at reproducing a simplified task of a system. They tend to be rather useful for Estonia, because they do neither assume perfect markets nor optimal consumer behaviour, but allow scenario analysis for future pathways.

Finally, toolbox models which are mainly bottom-up accounting type models, having the advantage that they are easy to use, which increases their usefulness for Estonia where users do often not have the same financial and training possibilities as in the other countries. The main disadvantage of toolbox models is that all important variables are indicated exogenously as parameters in future scenarios.

Backcasting models are less useful for this country.

Concerning the mathematical approach, linear programming has a clear advantage in that it allows for simple programming and can easily be understood by planners because no special expertise is needed. In this case the problem can be solved in a straightforward way by using standard algorithms.

In practice, it is not feasible to develop own models for energy planning exercises by energy planners and researchers, more effective to use existing models. Energy sector models that used widely across several countries for carrying out their economic and energy sector planning are presented in Table 3 and divided by the analytical approach (top-down, bottom-up, hybrid).

The same energy planning models are presented in Figure 9 and divided by the methodology.

It was reviewed a wide range of models that are presented in Table 3 and it was selected ten existing energy models that have the bottom-up or hybrid approach, linear programming and by the methodology are simulation, optimization and toolbox models. The selected energy planning models are given in Table 4 and divided by the analytical approach and methodology. The main characteristics of them are given in Table 5 and short description is provided below [II].

Generally, recent models offer an integrated approach in the sense that they combine several specific purposes, although some of models focus on one aspect only (such as some utility expansion models or environmental impact models).

In the next Chapter it is given a brief overview of the selected energy planning models existing today, including EFOM, TIMES, LEAP, MARKAL, MESAP, MESSAGE, MIDAS, PowerPlan, RETscreen and EnergyPlan.

Table 2. Energy model characteristics

	Macro-economic models	Energy equilibrium models	Optimization models	Simulation models	Spreadsheet models
Timeframe	Short to medium term	Medium to long term	Short to long term	Short to long term	Short to long term
Level of detail	Low, High	Low	High	Partially high	Technically specific
System boundaries	Entire economy	Entire economy	Energy system	Energy system	Entire economy
Flexibility in terms of technically detailed questions	Low	Low	High, dependent upon the level of detail of the tech. database	High for limited complexity	High
Theoretical foundation	Historical analysis of macro-economic interaction matrix	Neo-classical	Optimization with regard to tech.-economic criteria	Primarily tech. determinism of energy systems	Primarily tech. determinism of energy systems
Implementation of the modeling	Econometric estimation of the interconnections of the matrix	Decisions corresponding to nesting and elasticities	Technological database with optimization algorithms	Technological database, expert knowledge	Technological database
Strengths	Broad empirical foundation, sectoral disaggregation	Closed theoretical structure	Applicable to tech. total sys. Flexible application possibilities	Also usable without targeted entities for optimization	Applicable to tech.systems. Flexible application possibilities
Weaknesses	Does not represent specific technologies. No long-term planning	Small empirical basis, often low level of sectoral differentiation	Implicitly rational optimization decisions, strongly influenced by bounds	Economic influences underrepresented, based considerably on the quality of expert knowledge	For local applicability. Variables are indicated exogenously as parameters in future scenarios

Table 3. Energy planning models and their dividing by the analytical approach

	Models	Top-down	Bottom-up	Hybrid
1	AIM (Asian-Pacific Integrated Model)			X
2	BRUS (Brundtland Scenario)		X	
3	EFOM (Energy Flow Optimization Model)		X	
4	ENPEP (Energy and Power Evaluation Program)		X	
5	GEM-E3 (General equilibrium model)	X		
6	IMAGE/TIMER (TARGETS-IMAGE Energy Regional Model)			X
7	LEAP (Long-range Energy Alternatives Planning)		X	
8	MARIA (Multiregional Approach for Resources and Industry Allocation model)	X		
9	MARKAL (MARket ALLocation)		X	
10	MARKAL-MACRO (a simplified energy-economy model)			X
11	MEGEVE-E3ME (General energy–environment–economy mode)	X		
12	MERGE (Model for Evaluating Regional and Global Effects of GHG Reductions Policies)			X
13	MESAP (Modular Energy System Analysis and Planning software)			X
14	MESSAGE III (Model for Energy Supply Systems Analysis and General Environment)		X	
15	MIDAS (Multinational Integrated Demand And Supply)			X
16	MiniCAM (Mini Climate Assessment Model)			X
17	MURE/ODYSSEE (Measures d'Utilisation Rationelle de l'Energie)		X	
18	NEMS (National Energy Modelling System)			X
19	POLES (Prospective Outlook on Long-term Energy Systems)		X	
20	PowerPlan (Interactive simulation model)		X	
21	PRIMES (Partial equilibrium model)			X
22	RETScreen (Renewable Energy Technology Screening)		X	
23	SGM (Second Generation Model)	X		
24	TIMES ((The Integrated MARKAL-EFOM System)		X	
25	WEM (World Energy Model)			X

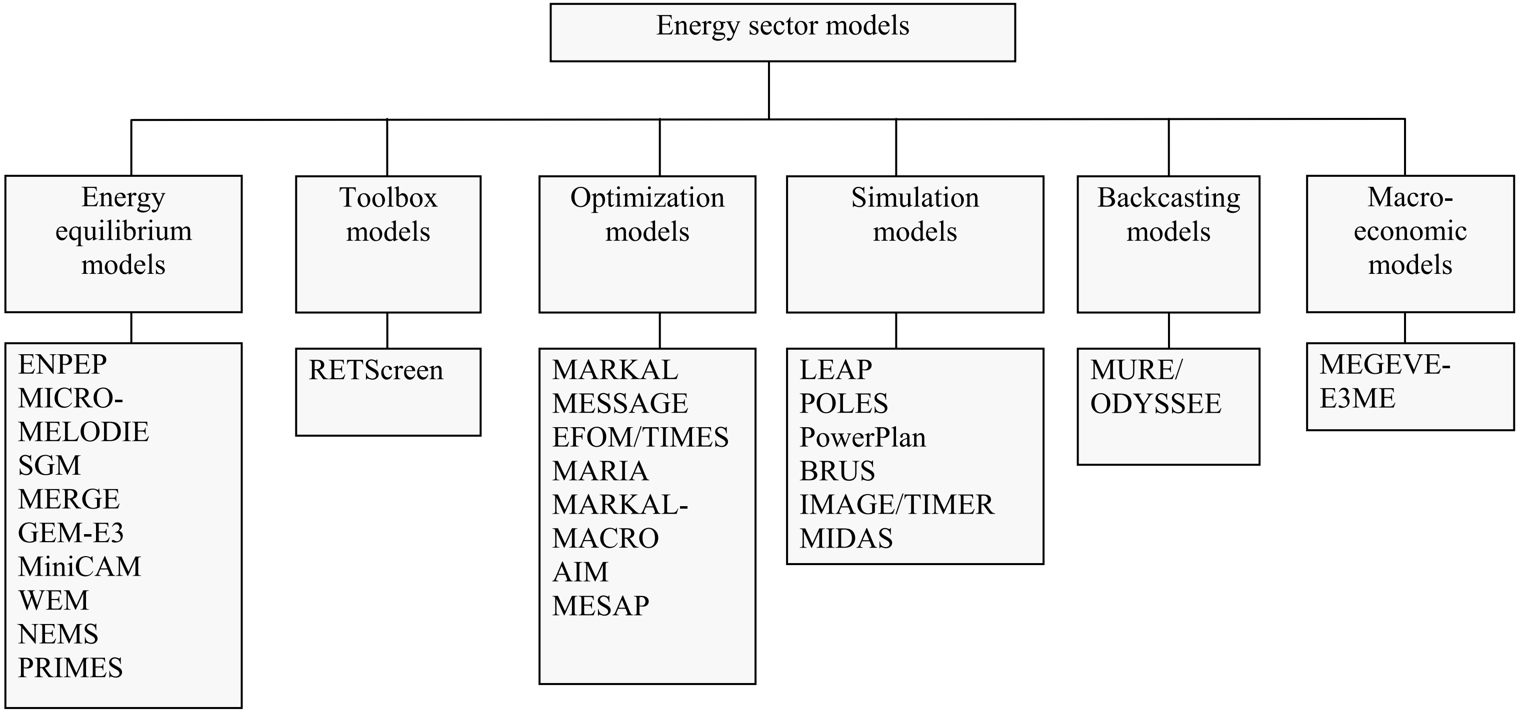

Figure 9. Energy planning models and their dividing by the methodology

Table 4. Existing energy planning models and dividing them by the analytical approach and methodology

	Models	Bottom-up	Hybrid	Optimization	Simulation	Toolbox
1	EFOM (Energy Flow Optimization Model)	X		X		
2	TIMES (The Integrated MARKAL-EFOM System)	X		X		
3	LEAP (Long-range Energy Alternatives Planning)	X			X	
4	MARKAL (MARket ALLocation)	X		X		
5	MESAP (Modular Energy System Analysis and Planning software)		X	X		
6	MESSAGE (Model for Energy Supply Systems Analysis and General Environment)	X		X		
7	MIDAS (Multinational Integrated Demand And Supply)		X		X	
8	PowerPlan (Interactive simulation model)	X			X	
9	RETScreen (Renewable Energy Technology Screening)	X				X
10	EnergyPlan		X		X	

Table 5. Energy planning models and the main characteristics

	Models	Developer	Home page	Geographic applicability	Data requirements	Default data included	Time horizon	Reference materials	Language
1	EFOM	European Union	-	Local, national, regional, global	Medium-high	Detailed description of energy supply and end-uses technologies	Medium to long term	Description in some literature	English
2	TIMES	IEA/ETSAP (Energy Technology System Analysis Project)	www.etsap.org	Local, national, regional, global	Medium-high	Detailed description of end-uses and (renewable) energy technologies possible	Medium to long term	Manual available to registered users	English
3	LEAP	Stockholm Environment Institute	www.energycommunity.org	Local, national, regional	Low-medium	Database with costs, performance and emission factors	Long term	Manual and training materials free on web site	English, French, Spanish, Portuguese, Chinese
4	MARKAL	IEA/ETSAP (Energy Technology System	www.etsap.org	Local, national, regional, global	Medium-high	Detailed description of end-uses and (renewable)	Long term	Manual available to registered users	English

	Models	Developer	Home page	Geographic applicability	Data requirements	Default data included	Time horizon	Reference materials	Language
		Analysis Project)				energy technologies possible			
5	MESAP	IER, Stuttgart University, Germany	-	Local, national, regional, global	Low-medium	Database with fuel costs and emission factors	Long term	Description in some literature	English
6	MESSAGE	IIASA (International Institute for Applied Systems Analysis) Austria	http://www.iiasa.ac.at	Local, national, regional, global	Medium-high	Database with conversion factors	Medium to long term	Description free on web site	English
7	MIDAS	European Union	http://www.e3mlab.ntua.gr/	Local, national, regional, global	Low-medium	Database with fuel costs and emission factors	Long term	Description in some literature	English
8	PowerPlan	Center for Energy and Environmental Studies University of Groningen	http://www.fwn.rug.nl/ivem/soft.htm	Local, national, regional	Low-medium	Database with fuel costs and emission factors	Medium to long term	Manual and demo version free on web site	English, Dutch

	Models	Developer	Home page	Geographic applicability	Data requirements	Default data included	Time horizon	Reference materials	Language
9	RETScreen	Natural Resources Canada	www.retscreen.net	Local	Technology specific	Extensive defaults: weather data, products, costs, etc.	One year in steps of one hour	Manual and training materials free on web site	Multiple
10	EnergyPlan	Sustainable Energy Planning Research Group at Aalborg University	http://energy.plan.aau.dk/	Local, national, regional	Low-medium	Database with costs, distribution and emission factors	Primarily static analysis	Manual and training materials free on web site	English

2.4 The overview of existing energy models

2.4.1 EFOM

EFOM, Energy Flow Optimisation Model, is national dynamic optimization models, representing the energy producing and consuming sectors in each region. They optimize the development of these sectors under given fuel import prices and useful energy demand over a pre-defined time horizon. The development of national energy systems can be subject to energy and environment constraints like availability of fuel, penetration rates of certain technologies, emission standards, and emission ceilings. The model databases contain a wide range of conversion and end-use technologies such as conventional technologies, renewable energy technologies, efficient fossil fuel burning technologies, combined heat and power technologies, and energy conservation technologies in the demand sectors.

EFOM was originally developed in a European Community research program in the 1970s. EFOM has been applied to all member countries of the European Union as well as many other countries, including Russia, Mexico and China. The EFOM is a multi-period model, which can cover a study time span of 40 years.

EFOM has been extended by an environmental module (EFOM-ENV), which includes emission reduction technologies with negative emission coefficients [12].

The the Energy Technology System Analysis Programme (ETSAP) community develops a new model (TIMES) that already has all the features that EFOM had and also combines aspects of MARKAL model.

2.4.2 TIMES

TIMES (The Integrated MARKAL-EFOM System) is a recent development in the evolution of the MARKAL framework, created by the ETSAP of the IEA. Like its predecessor, TIMES is a dynamic linear optimisation framework that finds the least-cost solution under given constraints such as annual or cumulative emission levels. It presupposes perfect foresight and parametric data sources. Due to increased model flexibility, TIMES allows for analysis of many problems which required undesirable compromises or were beyond the analytical limit [13].

2.4.3 LEAP

LEAP, Long range Energy Alternatives Planning, is a scenario-based energy-environment modeling tool. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price and so on. LEAP has been used to develop local, national and regional energy strategies, conduct GHG mitigation assessments, and train professionals in sustainable energy analysis. LEAP is an accounting tool that balances production and consumption of energy in an energy system model.

LEAP is deterministic, in the sense that all outcomes are specified by the user. Based on the assumptions provided by the user, LEAP balances the energy flow equations, thereby identifying the energy transformation and primary energy supply requirements.

LEAP results are generated in annual increments and presented as time series data. Time horizons will vary but LEAP is most commonly used for long term (more than 20 years) analysis.

LEAP was developed in Stockholm Environment Institute. LEAP has been adopted by hundreds of organizations in more than 150 countries worldwide. Its users include government agencies, academics, non-governmental organizations, consulting companies, and energy utilities. It has been used at many different scales ranging from cities and states to national, regional and global applications [14].

2.4.4 MARKAL

MARKAL, MARKet ALlocation, is a family of bottom-up energy system models that depicts both supply and demand. MARKAL provides policy makers and planners in the public and private sector with extensive detail on energy producing and consuming technologies, and it can provide an understanding of the interplay between the macroeconomy and energy use. As a result, this modeling framework has helped national and local energy planning, and the development of carbon mitigation strategies.

The model has been widely used in almost 40 countries, including developed, transitional and developing economies. MARKAL was originally designed to develop a strategy for research, development and demonstration for the International Energy Agency (IEA). The characteristics of future energy technologies were estimated and the influence of these technologies was analysed for several countries through various scenarios. MARKAL was developed at The Brookhaven National Laboratory in the USA and at Kernforschungsanlage Jülich in Germany. Available resources, economic, technical and environmental characteristics of technologies together with useful energy demands are the main input parameters in a MARKAL model.

The modelling horizon in MARKAL can be divided in up to sixteen periods of equal lengths. Due to new installations and decommissioning of old capacity, the market shares of different technologies vary throughout the periods. Model constraints include annual energy carrier balances, seasonal district heating balances, diurnal electricity balances and annual availability and demand equations.

MARKAL has been expanded to be a family of modelling systems. It has been linked to the top-down model MACRO, allowing the evaluation of the interaction between technology policies and market instruments. MARKAL-MACRO is a simplified energy-economy model, with detailed description of technologies. MARKAL-MICRO and MARKAL-ELASTIC_DEMAND (MED) are steps closer towards a partial equilibrium model, in which useful energy de-mand has been replaced, respectively, with non-linear and step-wise demand curves. The equilibrium between supply and demand is calculated by maximising the sum of consumer and producer surplus [10].

2.4.5 MESAP

MESAP (Modular Energy System Analysis and Planning software) is a modular energy planning package developed with the specific needs of developing countries in mind. It is designed as a flexible planning package providing energy analysts and planners with tools to perform complex energy analysis. It consists of basic techniques for energy planning, a set of tested energy modules, and data management and processing software. At the heart of MESAP is a network-oriented database. Its objective is to assist in energy and environmental policy analysis and planning [12].

2.4.6 MESSAGE

MESSAGE, Model for Energy Supply Strategy Alternatives and their General Environmental impact, is generally used for the optimization of energy supply systems. However, other systems supplying specified demands of goods, which have to be processed before delivery to the final consumer, could be optimized. The objectives include resource extraction analysis, estimation of import/export of energy, energy conversion analysis, energy transport and distribution analysis, final energy utilization by consumer analysis, recommendations for environmental protection policy and investment policy, and analysis of opportunity costs.

MESSAGE was created at IIASA (International Institute for Applied Systems Analysis) in Austria. MESSAGE was originally used for a study, in which seven world regions were analysed for a 50-year time horizon, divided into several periods. Like MARKAL and EFOM, also MESSAGE can be used to describe the overall energy supply system with resource extraction, import and export, commodity flows, conversion, distribution and end-use of energy. The modelling horizon is divided into periods, which can vary in length. Each period is represented by a typical year, which can be divided into load regions. A typical division includes winter, intermediate and summer days, which each subdivides into three load regions of arbitrary length.

The model’s current version, MESSAGE IV, is a UNIX based system that provides information on the utilization of domestic resources, energy imports and exports and trade-related monetary flows, investment requirements, the types of production or conversion technologies selected, pollutant emissions, inter-fuel substitution processes, as well as temporal trajectories for primary, secondary, final, and useful energy. MESSAGE has recently been expanded to include endogenous learning for various technologies using Mixed Integer Programming (MIP) approach. Another important model development includes extension of the model to cover all six Kyoto GHGs, their drivers and mitigation technologies [15].

2.4.7 MIDAS

MIDAS is a large-scale energy system planning and forecasting model. It performs dynamic simulation of the energy system, which is represented by combining engineering process analysis and econometric formulations. The model is used for scenario analysis and forecasting. MIDAS covers the whole energy system and ensures, on an annual basis, the consistent and simultaneous projection of energy demand, supply, pricing, and costing, so that the system is in both quantity- and price-dependent balance. The model output is a time-series of detailed EUROSTAT energy balance sheets, lists of costs and prices by sector and fuel, and a set of capacity expansion plans including emission data [16].

2.4.8 PowerPlan

PowerPlan is an interactive simulation model with which a future for the electricity supply system can be planned. PowerPlan is a so-called forecasting model: given an existing power system and year, an electricity supply system future will be simulated. It is thus not an optimization model, but a model from which the consequences of decisions can be evaluated (a "What – If" model) [17].

2.4.9 RETScreen

The RETScreen International Clean Energy Project Analysis Software is the leading tool specifically aimed at facilitating pre-feasibility and feasibility analysis of energy technologies. The core of the tool consists of standardized and integrated project analysis software, which can be used worldwide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of proposed energy efficient and renewable energy technologies.

Each RETScreen technology model (e.g. Combined Heat & Power Project, etc.) is developed within an individual Microsoft® Excel spreadsheet "Workbook" file. The Workbook file is in-turn composed of a series of worksheets. These worksheets have a common look and follow a standard approach for all RETScreen models. In addition to the software, the tool includes: product, weather and cost databases; an online manual; a Website; an engineering textbook; project case studies; and a training course [18].

2.4.10 EnergyPlan

The EnergyPlan model is a computer model for Energy Systems Analysis. The main purpose of the model is to assist the design of national energy planning strategies on the basis of technical and economic analyses of the consequences of different national energy systems and investments. The model can be used for different kinds of energy system analyses: technical analysis, market exchange analysis and feasibility studies [19].

2.5 Application of existing models

The selected ten energy planning models have been used and applied to various practical cases. This Chapter presents the overview of applications of selected models.

The effects on the entire energy system by a reduction in the amount of imported energy are studied by applying the EFOM model to the energy situation in Denmark [20] and for investigation of emission control strategies for Turkey [21].

TIMES model is usually applied to the analysis of the entire energy sector, but may also be applied to study in detail single sectors (the electricity and district heat sector). Using the TIMES framework there were developed several works for different countries: an energy system model for the Southern African Development Community region [22], the Nordic Electricity Production System [9], estimation of CO2 marginal abatement costs for Portugal [23], and several works of optimisation the electricity, heat and natural gas markets of the 25 trading regions in [24], [25], [26].

Hundreds of government agencies, academic organizations, utilities and consulting companies worldwide use LEAP for a variety of tasks including, energy forecasting, greenhouse mitigation analysis, integrated resource planning, production of electricity and heat energy sectors and energy scenario studies. Numerous countries have used LEAP to prepare greenhouse gas mitigation assessments as part of their initial national communications to the United Nations Framework Convention on Climate Change. The Department of Energy of the Government of the Philippines represents National Energy Plan [27] and scenarios for five cities in South Africa have been modeled using LEAP [28]. LEAP model was used in comparison of scenarios of oil shale long term trends in the report of Estonian Electricity Sector Development Plan until 2018 [6].

MARKAL is a well-known model in Estonia for modelling entire energy sector. The analysis has been carried out using the Estonian MARKAL model [29], [30], [31], [32]. Recently were defended two doctoral thesis in Tallinn University of Technology based on MARKAL calculations [33], [34]. The MARKAL model was developed in China, where the model represents all energy vectors of the Chinese energy balance [35], [36].

An industrial module was developed to form part of the applicable energy system analysis tools, namely a Reference Energy Model for PlaNet (PlaNet: Planning Network) under the MESAP (Modular Energy System Analysis and Planning Environment) for Slovenia [37] and for neighbouring Latvia [38]. The energy supply scenarios adopted in [39], where it provided a blueprint showing how to apply existing technologies to halve global CO2 emissions by 2050, whilst allowing for an increase in energy consumption.

MESSAGE was used in [40] for the entire energy supply system in countries of the Baltic States. Report on emissions scenarios [41], where was presented extensive historical data about economic development and energy systems with empirically estimated equations of trends to determine future structural change. The publication [42] presents the study which evaluates the alternative energy supply strategies with user defined constraints on fuel availability, environmental regulations and so on in India.

MIDAS covers the whole energy system, including energy demand by sector and fuel, power generation, oil refineries, natural gas, solid fuel production, imports and energy market prices. The results of MIDAS application in France and EU are given in [43], [44].

PowerPlan model is simulating a countries' power sector and its emissions. The study based on scenarios developed in PowerPlan was carried out in China's power sector [45], [46].

RETScreen model includes the whole energy sector and the list of applications of RETScreen model is given in [47]. Numerous examples for implementing commercially viable energy efficient and renewable energy technologies around the world such as Wind Farm in Ireland, Solarwall on High School in Northern Canada, Photovoltaic Water Pumping System in Africa, Solar Water Heating at Vancouver International Airport and many others. It was made the investigation of future project of waste incineration plant building at Iru Power Plant in Estonia [48].

EnergyPlan model has been used for modelling the heat, electricity energy sector. Analysis of individual house heating systems conducted by use of the EnergyPlan model presents in [49]. In 2005-2007, the EnergyPlan model was used in the EU-funded project DESIRE (Dissemination Strategy on Electricity Balancing for Large Scale Integration of Renewable Energy). In six regions in Denmark, Germany, the UK, Poland, Spain and Estonia, models of the electricity supply were made and the magnitude of CHP regulation systems was evaluated against other relevant measures including the expansion of interconnectors [50]. A comparative study of two energy system analysis models (EnergyPlan, H2RES) both designed for the purpose of analyzing electricity systems with a substantial share of fluctuating renewable energy [51].

3 ADAPTABLITY OF ENERGY PLANNING MODELS FOR ESTONIAN ENERGY SECTOR

The different types of existing energy planning models were reviewed and ten existing energy models selected for more detailed analysis: they have the bottom-up or hybrid approach, linear programming and by the methodology are simulation, optimization and toolbox models.

The next weighty argument for further selection of models for testing was their free availability and distribution in personal and academic projects. Table 6 is presenting the energy planning models documentation and download availability.

Table 6. Energy planning models documentation and download availability

	Models	Model's Documentation	Freely available
1	LEAP	X	X
2	MARKAL/ TIMES	X	40 00-200 000 EEK depending on type of client (including GAMS, solver & interface)
3	MESAP	X	No information
4	MESSAGE	X	Available for users with additional request

	Models	Model's Documentation	Freely available
5	MIDAS	X	No information
6	PowerPlan	X	Only freely available demo version
7	RETScreen	X	X
8	EnergyPlan	X	X

The Chapter 3 presents the testing of freely available for users: RETScreen, EnergyPlan and LEAP. MESSAGE model is available for users with additional request of entering data and it was not considered in this work. The detailed analysis and the concept of MESSAGE model is given in [40]. PowerPlan model has only freely available demo version.

3.1 Adaptability of RETScreen and EnergyPlan models

For investigation the opportunities of new heat energy supply alternatives in Narva there were tested two energy planning models: EnergyPlan and RETScreen® International models. These models were analysed and the scenarios were calculated for comparing the difference between the results of two chosen models and finding out whether the results reliable.

The heat energy supply alternatives modelling in Narva city was made for investigation the feasibility and economical reasonability of the oil shale condensing extraction turbine block usage comparing with the other alternatives, such as biomass CHP, natural gas CHP and boilerhouse. The CHP usage could increase heat production part based on CHP and decrease fuel consumption. The selection of scenarios was based on local oil shale availability from this region, where oil-shale-based Narva Power Plant works, and secondly to compare cogeneration technology and boilerhouse economy.

The description of these models is provided in Chapter 2.4.9 and 2.4.10.

The RETScreen energy model is more useful for single new energy capacity planning as well as EnergyPlan model. Also the RETScreen model has the possibility of detailed technical equipment selection and the financial indicator's calculation.

There were generated and analyzed four scenarios (pre-feasibility studies) of building new capacity in Narva city:

- Scenario 1: Oil shale CHP unit at Balti PP
- Scenario 2: CHP unit, where the main fuel is natural gas
- Scenario 3: Boilerhouse, where the main fuel is natural gas
- Scenario 4: Biomass/Peat CHP unit.

The annual heat energy demand in Narva city is about 475 GWh, taking into account heat supply with hot water and technological steam. Expected units thermal capacity is about 170-175 MW and electrical capacity is about 60-65 MW. The annual electricity production from the units in Scenario 1, 2 and 3 would be approximately 160 GWh. The main input data for these analyses are the production of electricity and heat, fuel types, fuel costs, efficiency of processes and the investments of projects according to the available data. The investment and other costs are informative and needed further research for more accurate analysis. Also it was used the existing library of distribution data of Nord Pool electricity prices in 2006 in the EnergyPlan model. For all four scenarios it was calculated and compared the primary energy consumption, CO_2 emissions and production price.

The calculations made in the EnergyPlan and RETScreen model and their results are presented in simplified tables (Table 7, 8) and comparing of the results of two energy planning models is presented in Table 9. The simplified tables use the relative information about fuel, investment, primary energy and production prices considering that in case of the changes in fuel and investment costs will be the same price relations. The production prices include the electricity and heat energy production prices and could be put together because of the same combined power plant total output. Generally, the RETScreen model uses hybrid method for calculation the heat and electrical energy price, where variable costs are shared: fuel, electricity and environmental charges in accordance with the physical method as well as fixed costs in accordance with heat and electricity production. The electricity price could be the input parameter also. The Energy Plan model uses the existing library of electricity and heat prices. In this case it was used the existing library of distribution data of Nord Pool electricity prices in 2006.

Table 7. EnergyPlan model's results

EnergyPlan	Fuel, EEK/MWh	Investments, mln.EEK/MW	Production price, EEK/MWh	Primary energy consumption per production, GWh/GWh	CO_2 emission, Mt
1. Scenario (Oil shale unit at Balti PP)	54	1.3	1 080	1.42	0.33
2. Scenario (CHP - main fuel is nat.gas)	305	1.0	1 165	1.19	0.15
3. Scenario (Boilerhouse - main fuel is nat.gas)	305	0.5	665	0.85	0.11
4. Scenario (Biomass/Peat CHP)	62	1.0	861	1.23	0,00

Table 8. RETScreen model's results

RETScreen	Fuel, EEK/MWh	Investments, mln.EEK/MW	Production price, EEK/MWh	Primary energy consumption per production, GWh/GWh	CO_2 emission, Mt
1. Scenario (Oil shale unit at Balti PP)	54	1.3	1 255	1.39	0.32
2. Scenario (CHP - main fuel is nat.gas)	305	1.0	1 177	1.15	0.15
3. Scenario (Boilerhouse - main fuel is nat.gas)	305	0.5	665	0.81	0.10
4. Scenario (Biomass/Peat CHP)	62	1.0	870	1.18	0.00

The difference between EnergyPlan and RETScreen model's results for production price is approximately 5 % in Scenarios 1, 2 and 4, primary energy consumption per production for all scenarios is about 4 % and CO_2 emissions in Scenarios 1, 2 and 3 is 4,3 % (see Table 9).

Table 9. EnergyPlan and RETScreen model's results comparing

EnergyPlan vs. RETScreen	Production price, EEK/MWh		Primary energy consumption per production, GWh/GWh		CO2 emission, Mt	
1. Scenario (Oil shale unit at Balti PP)	-175	-14.0 %	0.03	2.0 %	0.01	3.7 %
2. Scenario (CHP - main fuel is nat.gas)	-12	-1.1 %	0.04	3.3 %	0.01	3.5 %
3. Scenario (Boilerhouse - main fuel is nat.gas)	0	-	0.04	4.4 %	0.01	5.6 %
4. Scenario (Biomass/Peat CHP)	-9	-1.1 %	0.05	4.2 %	0.00	-

The higher production price in Table 8 comparing the results of Table 7 at the same investment and with better use of primary energy is explained by the more accuracy and the difference in the characteristics of the equipment of the second model (RETScreen). In this analysis the investment and other costs are informative and needed further research for more accurate analysis.

Using RETScreen Software in the Financial Summary worksheet it was calculated several financial feasibility indicators such as internal rate of return IRR, the net present value (NPV) and simple payback of the projects.

The internal rate of return IRR is the discount rate that causes the NPV of the project to be zero. It is calculated by solving the following formula for IRR:

$$0 = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n}, \qquad (6)$$

where N is the project life in years and C_n - the cash flow for year n.

The net present value NPV of a project is the value of all future cash flows, discounted at the discount rate, in today's currency. It is calculated by discounting all cash flows as given in the following formula:

$$NPV = \sum_{n=0}^{N} \frac{\widetilde{C}_n}{(1+r)^n}, \qquad (7)$$

where $\widetilde{C}_n$ is the after-tax cash flow, r - the discount rate.

The simple payback SP is the number of years it takes for the cash flow (excluding debt payments) to equal the total investment, which is equal to the sum of the debt and equity:

$$SP = \frac{C - IG}{(C_{ener} + C_{capa} + C_{RE} + C_{GHC}) - (C_{O\alpha M} + C_{fuel})}, \qquad (8)$$

where C is the total initial cost of the project, IG - the incentives and grants, C_{ener} - the annual energy savings or income, C_{capa} - the annual capacity savings or income, C_{RE} - the annual renewable energy production credit income, C_{GHC} - the GHG reduction income, $C_{O\alpha M}$ - the yearly operation and maintenance costs incurred by the clean energy project, C_{fuel} - the annual cost of fuel or electricity [17].

According to the pre-feasibility study using given input data all of scenarios have positive NPV, IRR and could be applicable for more detail analysis. The most attractive scenario is Scenario 4 with building biomass/peat CHP; simple payback is about 7 years. The building CHP or boilerhouse (Scenario 2, 3) using natural gas could be under the question, because of the high cost of fuel, despite of less initial investment costs of the project in Scenario 3 the payback is 11 years. The payback of Scenario 2 is 13 years. The usage of oil shale as the main fuel of unit in Scenario 1, where payback period is 9 years, could be competitive and has clear advantages: the local fuel availability and stable supply, the possibility to generate electricity additionally, the location of new unit in the existing power plant. The results of the financial feasibility indicators are presented in Figure 10.

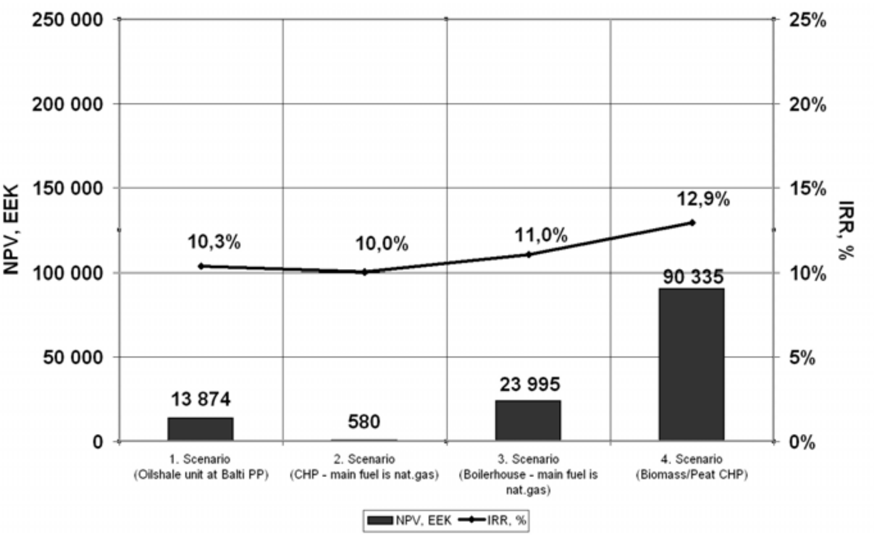

Figure 10. The results of financial indicators

The RETScreen energy model has more detailed input requirements for new energy capacity planning and therefore it could be more useful for such kind of analyses. The EnergyPlan model is more useful for whole country energy balance planning and for the new capacities does not have the opportunities to calculate the financial feasibility indicators and payback of the project. The EnergyPlan model does not have the possibilities to input the external assumption information and data of sectors such as industry, mining and etc., comparing with LEAP model. But both of the models equally could be used for the pre-feasibility study of new capacity planning projects. The results of reviewed models have marginally difference; the models are indicative for scenarios development and could be useful for comparing the fundamental technological processes. Also the advantage of using these models is that they allow getting reliable results using comparatively low input data [III].

3.2 Adaptability of LEAP model

For elaborating the scenarios of development of Estonian electricity production system during the period 2009-2035 in the conditions mentioned above the LEAP model was selected as the preferred framework, where the most essential reasons of selecting were free using of model and training materials, public technical support and discussion, user friendly interface, it allows for transparent arrangement of the data, various possible scenarios and can be developed energy system configurations. The main benefit of LEAP is that it is a tool that helps the user to combine and assess data in a consistent framework. This makes it easier to organize the data in an intuitive and accessible manner, and to get a grasp on the information. LEAP calculations and the results of scenarios are presented in this Chapter.

3.2.1 LEAP data requirements

3.2.1.1 Demographic data

Estonia's population annual growth rate of about 1 % per 5 years during the period from 1950 to 1990 and by the year 1990 reaches the 1.6 million mark. After the independence regaining in 1991 the population the annual decrease is about 0.9 %, today the population of Estonia is 1.3 million people and continues to decrease. Annual growth rate of population estimates approximately -0.4 % per year by the year 2035 and the enumerated population 1.2 million people. Initial data of population and demographic trends in Estonia are shown in Table 10 [2].

Table 10. Demographic trends in Estonia

Year	Population, Thousands of people	Growth rate of total population, %	Crude birth rate, Births per 1 000 people	Crude death rate, Deaths per 1 000 people	Total fertility rate Units: Children per woman	Life expectancy at birth, both sexes Units: Years	
						Male	Female
1950-1955	1 131	1.04	17	13	2.06	61.7	68.3
1955-1960	1 187	0.94	17	11	1.99	64.2	71.4
1960-1965	1 253	1.20	16	11	1.94	65.0	73.4
1965-1970	1 328	1.12	15	11	2.02	65.7	74.2
1970-1975	1 400	0.96	15	11	2.15	65.7	74.7
1975-1980	1 453	0.56	15	12	2.06	64.5	74.4
1980-1985	1 497	0.69	15	13	2.09	64.4	74.3
1985-1990	1 556	0.54	16	12	2.20	65.9	74.8
1990-1995	1 511	-1.70	11	14	1.63	62.6	74.0
1995-2000	1 400	-0.98	9	14	1.33	63.9	75.3
2000-2005	1 353	-0.38	10	14	1.39	65.1	76.7
2005-2010	1 330	-0.35	11	14	1.49	65.9	76.8

Year	Population, Thousands of people	Growth rate of total population, %	Crude birth rate, Births per 1 000 people	Crude death rate, Deaths per 1 000 people	Total fertility rate Units: Children per woman	Life expectancy at birth, both sexes Units: Years	
						Male	Female
2010-2015	1 307	-0.33	11	14	1.54	66.9	77.4
2015-2020	1 287	-0.34	11	14	1.59	68.8	78.4
2020-2025	1264	-0.41	10	14	1.64	70.1	79.3
2025-2030	1237	-0.45	9	14	1.69	71.7	80.0
2030-2035	1210	-0.44	9	14	1.74	72.9	80.6

After the independence regaining in 1991 the population decreases about 1 % and rural urban distribution has also undergone some structural changes. Its population in rural areas has more or less the same level of 30% during the years 1980-2008, whereas population in urban areas has decreased about the same 1 % during the period after independence regaining till today from 1.1 million to 0.9 million people. By the year 2035 rural-urban distribution of population estimates as 25 % or 0.3 million rural population and 75 % or 0.9 million for urban population. As indicated in Tables 11, the percentage shares of the population residing in urban and rural areas [2].

Tables 11. The percentage shares of the population in urban and rural areas

Year	Rural population, %	Urban population, %
1950-1955	48.4	51.7
1955-1960	44.4	55.6
1960-1965	40.6	59.4
1965-1970	36.9	63.1
1970-1975	33.7	66.3
1975-1980	31.3	68.7
1980-1985	29.8	70.3
1985-1990	29.0	71.0
1990-1995	29.4	70.6
1995-2000	30.3	69.7
2000-2005	30.8	69.2
2005-2010	30.8	69.2
2010-2015	30.3	69.7
2015-2020	29.2	70.8
2020-2025	27.7	72.3
2025-2030	26.0	74.0
2030-2035	25.1	74.9

The household size for rural and urban areas has been estimated based on the percentage of owner occupied housing units: 75 % or about 1.0 million households in rural and urban areas in base year 2008. The projected number of households in rural and urban areas will be calculated according the projections of population annual rate and urban-rural distribution annual rate.

3.2.1.2 Economic data

The gross domestic product (GDP) or gross domestic income (GDI), a basic measure of an economy's economic performance, is the market value of all final goods and services made within the borders of a nation in a year. Economic growth results from an increased production of goods and services leading to high income generation. This ultimately translates into improvement in the quality of life of the people in terms of various economic and social indicators such as enhanced purchasing power and improved access to quality education and health care services. GDP tracks the domestic economic activity in terms of the value added and income generated (in monetary terms) during a specified time period. Rapid growth of Estonian economy in last years, however, has made it difficult to keep inflation and large current-account deficits from soaring, putting downward pressure on the country's currency. The government has not given up on joining the euro, but has repeatedly postponed its euro adoption target. Estonia's economy slowed down markedly and fell into recession in middle of year 2008, primarily as a result of an investment and consumption slump following the bursting of the real estate market bubble. The GDP is about 248 billion Estonian kroons in base year 2008 and the projections of GDP growth according to Eesti Pank's forecast.

According to the Statistics Estonia at the beginning of June, GDP decreased 15.1 % in the first quarter of 2009. The decline is expected to be stronger in the first half of the year. For the input data about gross domestic product growth projections it was used the Eesti Pank's forecast that shown in Table 12 [52].

Table 12. Eesti Pank's GDP growth forecast

GDP	Eesti Pank's forecast	2008	2009*	2010*	2011*
GDP (EEK bn)	Base scenario	248	214	204	214
	Optimistic scenario	248	226	218	238
	Pessimistic scenario	248	208	184	178
Real GDP growth (%)	Base scenario	-3.6	-12.3	0.2	4.7
	Optimistic scenario	-3.6	-8.4	1.2	5.4
	Pessimistic scenario	-3.6	-15.3	-4.6	1.9

* Forecast

Trends in sectoral composition of gross domestic product and projections of sectoral composition of gross domestic product are given in Table 13.

Table 13. Sectoral composition of gross domestic product and projections

Sector	Sectoral composition of GDP in 2008, %	Sectoral composition projection of GDP in 2035, %
Agriculture	2.9	3
Industry	32.3	32
Services	64.8	65

3.2.1.3 General energy data

General energy data Chapter includes energy balances with data on energy consumption and production by sector or sub-sector. There are demands for five end-use sectors (agriculture, industry, transport, residential and commercial) have been considered in this analysis. The estimates of transmission and distribution sector and electricity generation data are presented in this Chapter. Further, the technology characteristics of various options in each supply- and demand-side sector are described.

Agriculture sector

There are about 830 000 hectares of used agricultural land in Estonia. The most important branch of agricultural production is livestock farming with the biggest share belonging to dairy farming.

According to Statistics Estonia, there are 245 400 bovine animals in Estonia, including 102 000 dairy cows, 379 500 pigs, 95 000 sheep and goats and 1 734 200 birds. The biggest number of bovine animals, including dairy cows, can be found in Järva County, West-Viru County and Pärnu County. Sheep are raised the most in Saaremaa.

Important plant production fields are growing cereals, oil cultures, potatoes and vegetables. The growth area of cereals has continued to increase during the last years, reaching up to more than 309 000 hectares. According to the data of 2008, summer cereal is grown on 253 000, winter cereal on 70 000 and rape on 77 000 hectares.

During recent years, the number of agricultural holdings has decreased and their structure changed. Change has also taken place in the structure of gender and age of the heads of the holdings and work load.

During 2003-2007, the number of agricultural holdings decreased 36.7 %; however, the average area of agricultural land of the holding increased 1.8 times (from 21.6 hectares to 38.9 hectares) [53].

Transport sector

Transport is a key factor for the economy as a whole. While transport is a sector servicing other areas of the economy, it is also the largest sector of the economy – in Estonia, the transport industry and its support service activities account for nearly 8 % of employment. The transport sector has significant impact on economic growth, social development and the environment.

According to the data of Statistics Estonia, in 2008 the usage of services of passenger transport enterprises decreased by about a tenth compared to 2007. The volume of carriage of goods decreased by a fourth compared to the previous year.

In 2008, the number of passengers carried by Estonian transport enterprises was over 193.4 million. 93 % of passengers used road transport (incl. city transport by buses, trams and trolley buses), 4 % sea transport, 3 % rail transport and less than 1% air transport.

Around 186.6 million passengers were carried in domestic traffic, the number of passengers decreased by a tenth compared to the previous year. 80 % of passengers in domestic traffic used city transport. The number of passengers in domestic traffic using buses, rail and sea transport decreased, but it increased in domestic flights.

The amount of passengers in international traffic was around 6.8 million, 5 % more than in 2007. The number of passengers in international traffic increased in sea, road and rail transport, but around a third less passengers used international flights compared to the previous year [54].

Industry sector

Textiles & Clothing

The textiles and clothing industry in Estonia is the country's second largest industrial sector, employing 14 000 people. Exports of clothing in particular have been expanding at a rapid rate, with Western Europe a leading target market. Cheap labour and infrastructure costs, as well as good local reputation, have attracted and continue to attract foreign investors.

Food & Food-processing

The food and food-processing sector has traditionally been one of Estonia's largest industry sectors, employing 5 % of the country's workforce or 21 500 people. The output of this sector represents 25 % of total Estonian industrial output, with approximately one third of this production exported. The main export products include meat, fish, dairy products and beverages.

Chemicals

The chemical industry, and in particular oil shale processing and fertiliser manufacturing, has long been one of Estonia's most important industrial sectors, accounting for 4.4 % of manufacturing output in 2003. 76 % of chemical production was exported in 2003, with the main export articles including dyes, fertilizers, pharmaceutical products and organic/inorganic chemicals. The chemical industry has attracted the fourth largest stock of foreign direct investment stock, after the food processing, wood and textiles industries.

Transport & Logistics

Approximately 7.5 % of the labour force in Estonia is employed in the transportation and road management sectors, and the share of national GDP generated by the transportation and telecommunications sectors now stands at 10.5 %. The cargo sector is dominated by railway transport, which accounts for 70 % of all carried goods, domestic and international. Road transport accounts for 90 % of all passengers.

Timber Processing

In common with other industrial sectors, the Estonian wood processing industry experienced extensive restructuring in the early 1990s. In 2003, 22.2 % of sales of all Estonian enterprises came from the sales within this sector. Wood processing companies are located all over the country, with principal concentrations located near Tallinn, Tartu, Pärnu and Rakvere. A good price-quality ratio ensures the competitiveness of products supplied by Estonian wood processing companies in developed markets. As a result, products are cheaper than those of Western competitors. The quality of Estonian wood products compares favorably to competitors in other Central or Eastern European countries.

Engineering & Metalworking

Estonian engineering is a developing modern industry with comprehensive ties to engineering clusters in Scandinavia and Western Europe. In 2004, the Estonian engineering and metal working industry had an out put of over 740 million euro, which represents about 17 % of total national output. More than 20.000 people are employed by about 300-400 companies, the majority of which are small and medium-sized enterprises (SMEs). In terms of sector turnover, however, the largest companies dominate. Industry focus is increasingly on the more complex and value-added production, such as machine building and special tooling.

Electronics

The electronics industry is one of the fastest growing sectors in Estonia and a number of foreign multinationals have relocated, which has moved production towards less-labour intensive production and complex operations. About 300 companies currently employ approximately 13.000 people in this sector. Most of these companies are SMEs, which account for more than 50 % of sector turnover. In 1994 around 3.4 % of total Estonian manufacturing production was accounted for by the electronics industry, a figure that had grown to 6.9 % by 2003. This growth is forecasted to continue.

Construction

The construction industry is an important branch of the Estonian economy, contributing about 6.7 % to total GDP. This makes construction the fifth largest contributing sector to the Estonian national economic output [55].

As simplifying assumption the agricultural and industial sector were united.

Residential sector

In the year 2008, Estonia's 1.331 million people are living in about 1 million households. 69 % of these are in urban areas. The key data, that was taken mainly from [56], [57], is given below.

Urban Households

- All of Estonia's urban residents are connected to the electric grid, and use electricity for lighting and other devices.
- 100 % have refrigerators, which consume 500 kWh per year on average.
- The average urban household annually consumes 400 kWh for lighting.
- Other devices such as washing machines, VCRs/VCPs, music systems, TV, and fans annually consume 800 kWh per urban household.
- 70 % of Estonia's urban dwellers use electric stoves for cooking: the remainder use natural gas stoves. All households have only one type of cooking device.
- The annual energy intensity of electric stoves is 1.44 GJ per household, for natural gas stoves it is 60 cubic meters.

Rural Households

A recent survey of all rural households (both electrified and non-electrified) indicates the following types of cooking devices are used:

Cooking in rural Estonia is given in Table 14.

Table 14. Cooking in rural Estonia

Type of cooking	Share of Rural HH	Energy Intensity per Household
Natural gas stove	35 %	60 m^3
Wood stove	15 %	525 kg
Electric stove	50 %	1.2 GJ

- 100 % of rural households have access to grid-connected electricity.
- 95 % of the electrified rural households own a refrigerator, which consumes 500 kWh per year on average.
- All electrified rural households use electricity for lighting, which consumes 335 kWh per household. Only 5% of these households also use kerosene lamps for additional lighting, using about 10 liters per year.
- Other electric devices (TV, radio, fans, etc.), account for 111 kWh per household per year.

Projections for residential sector

Urban Households:

- By 2035, 75 % of Estonia's households will be in urban areas.
- Increased preference for electric stoves results in a 75 % market share by 2035.
- The energy intensity of electric and gas stoves is expected to decrease by half a percent every year due to the penetration of more energy-efficient technologies.
- As incomes rise and people purchase larger appliances, annual refrigeration intensity increases to 600 kWh per household by 2035.
- Similarly, annual lighting intensity increases to 500 kWh per household by 2035
- The use of other electricity-using equipment grows according to population growth projections.

Rural Households:

- As incomes will increase after economical crises, the energy intensity of electric lighting is expected to increase by 1 % per year.
- Refrigerator use in grid-connected rural homes is expected to increase to 97 % in 2010, and 100 % in 2035.
- Due to rural development activities the share of various cooking devices changes so that by 2035, electrical stoves are used by 70 % of households, the natural gas stoves usage decreases to 20 %. The remaining rural households use wood stoves.

Commercial sector

Commercial buildings in Estonia utilized a total of 1 million square meters of floor space in 2008.

- Total energy consumption for heating purposes was 0.18 million GJ in 2008.
- Electricity, natural gas and wood for the total heating energy divided as follows: 50 % electricity heating, 30 % natural gas and the remaining use wood for heating.
- Electric heaters have an efficiency of nearly 100 %, while natural gas boiler efficiencies average 90 % and wood boilers have 82 % efficiencies.
- Floor space in the commercial sector is expected to grow at a rate of 1 % per year.
- Due to expected improvements in commercial building insulation standards, the useful energy intensity (i.e. the amount of heat delivered per square meter) is expected to decline by 1 % per year until 2035.
- By 2035, natural gas boilers are expected to have reached a market penetration (i.e. share of floor space) of 50 %, while wood boilers are expected to decline to 15 % market share. Electricity heating fills the remaining requirements.

Transformation: Transmission and Distribution

This module represents electricity and transmission and distribution (T&D) losses and natural gas pipeline losses. Electricity T&D losses amount to 8 % of the electricity generated in 2008. In the projection these are expected to decrease to 7 % by 2035. Natural gas pipeline losses amount to 2 % in 2008, and are expected to decrease to 1.5 % by 2035.

Electricity Generation

The main figures and description of Estonian electricity sector is given in Chapter 1.1 and 1.2. It was summarized the existing power plant to the Table 15 and put the information on some of basic characteristics of the plants in 2008 in Estonia:

Table 15. Basic characteristics of the plants in 2008 in Estonia

Plant type	Installed capacity (MW)	Thermal Efficiency (%)	Dispatch Merit Order	Maximum Capacity Factor
Existing Oil Shale Units	1 393	30	1	80
Natural Gas PP	98	55	2	80
Wind	59	100	1	50
Hydro	3	100	1	70

The electricity system operates with a minimum planning reserve margin of 30 %, and the electric system currently has a low system load factor reflected in the system load curve shown below. The peak system demand in 2008 was 1 525 MW. System load curve in 2008 is given in Table 16 [58].

Table 16. System load curve in 2008

Hours, h	Percent of peak load, %
0	100
2000	95
3000	89
4000	59
5000	44
7000	34
7440	33
7880	32
8320	30
8760	30

3.2.2 Energy power system development scenarios

As a part of this thesis, there were presented the different scenarios of Estonian energy system development in the conditions of oil shale-based electricity supply shortage, taking into account the main engagements and figures of electricity sector by year 2020. The aim of this part is to a simplified model of Estonian energy system with a transparent structure. The purpose of the model is to demonstrate the usage of the model's features in connection with the Estonian electricity system. Afterwards, the model may serve as a basis for more accurate model of Estonia.

Using Estonia LEAP (Long-range Energy Alternatives Planning System) model were elaborated eight alternative scenarios:

1. *Reference scenario (REF)*

The Reference Scenario represents a today's situation of Estonia's energy sector. This scenario is characterized that the CFBC oil shale units will be renovated and the production of electricity is dominated by oil shale. The penetration of various renewable energy technologies such as wind and biomass power generation is considered as per the existing situation today. In the REF, the -12.3 % GDP growth rate in the year 2009 and the forecasts are according to Eesti Pank's revised forecast of the first quarter [52].

2. *Low-growth scenario (LG)*

This scenario assumes a low GDP growth rate of -15.3 % in the year 2009 relative to the -12.3 % GDP growth rate assumed in the REF scenario in the same year and the forecasts are according to Eesti Pank's revised forecast of the first quarter [52]. The impact of projected GDP growth rates will influence to the future trajectories of energy demand in this scenario. Electricity consumption in this scenario is estimated like increasing of 0.7 % annually. All other assumptions and other parameters are similar to the REF scenario.

3. *High-growth scenario (HG)*

This scenario assumes a high GDP growth rate of -8.4 % from year 2009 relative to the GDP growth rate of -12.3 % assumed in the REF scenario in the same year and the forecasts are according to Eesti Bank's revised forecast of the first quarter [52]. This scenario shows an optimistic view of the Estonian economy. Electricity consumption in this scenario is estimated like increasing of 1.6 % annually. All other assumptions and other parameters are similar to the REF scenario.

4. *Nuclear capacity scenario (NUC)*

In this study, nuclear-energy-based power generation has been included as per Eesti Energia plans. The installed capacity of nuclear power plants is 600 MW in year 2020. The nuclear energy - based power generation capacity is expected to be in the amount of 5 000 GWh per year from the nuclear power plan starting. Additional information about nuclear power plant scenarios is given in [33].

5. *Renewable energy scenario (REN)*

In this scenario, high penetration of renewable energy is considered. Amount of potential places are identified for wind-based power plants in the country such as offshore wind farms in Estonian waters and wind farm on the closed ash field at AS Narva Elektrijaamad. The availability capacity of wind power plants is assumed to increase till 618 MW by the year 2012 as compared to the existing 117 MW in 2009.

6. *Hybrid scenario (HYB)*

This scenario is a combination of the REF, REN, and NUC scenarios. It describes the energy forecast of the Estonian economy by incorporating the entire range of renovation and development of oil shale technologies, penetration of nuclear energy - based power generation technologies, the renewable energy sources and the starting up of new gas turbine with capacity of 100 MW after year 2012. The GDP growth rate is as in REF scenario.

7. *Low-growth-hybrid scenario (LHYB)*

This scenario combines a low GDP growth rate like in LG scenario and the HYB scenario with energy technologies development. This scenario is representative of the pessimistic scenario in low economic growth with the technological achievements.

8. *High-growth-hybrid scenario (HHYB)*

This scenario combines a high GDP growth rate like in HG scenario coupled with high efficiency levels, high nuclear capacity, and penetration of renewable energy as in HYB scenario. This scenario is representative of the most optimistic scenario in terms of both economic growth and technological achievements.

3.2.3 Model results and analyses

This Chapter presents the analytical results of the scenarios mentioned in previous Chapter. The results were obtained after running the Estonia LEAP (Long-range Energy Alternatives Planning System) model for eight alternative scenarios:

1. Reference scenario (REF) at -12,3 % GDP
2. Low-growth scenario (LG) at -15,3 % GDP
3. High-growth scenario (HG) at -8,4 % GDP
4. Nuclear capacity scenario (NUC) at -12,3 % GDP
5. Renewable energy scenario (REN) at -12,3 % GDP

6. Hybrid scenario (HYB) at -12,3 % GDP
7. Low-growth-hybrid scenario (LHYB) at -15,3 % GDP
8. High-growth-hybrid scenario (HHYB) at -8,4 % GDP

3.2.3.1 *Reference scenario results*

The results of Reference scenario are given in this Chapter.

Figure 11 presents sectoral primary energy demand that depends mostly on annual growth rate and increases annually 1.43 % during the calculation period (2009-2035), taking into account the economic crises of country in the REF. Generally sectoral energy demand is divided into four main sectors: commercial sector, transport, industrial sector and residential or household sector. The first highest contributor to the growth in sectoral energy consumption is increasing consumption in the industrial sector in the REF scenario during 2009-2035 annually by 1.66 %, in the residential sector by 1.07 %, in the transport sector by 0.66 % and in the commercial sector by 0.23 %. The requirements shown under the demand category shows only the primary energy required to meet domestic demands.

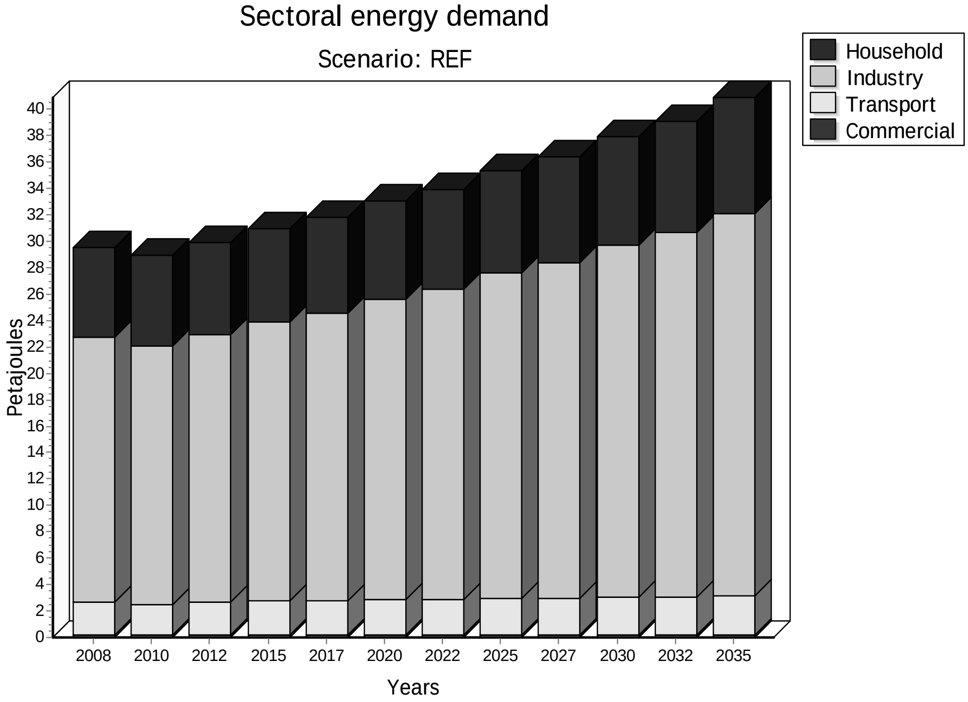

Figure 11. Sectoral energy demand: commercial, transport, industry and household

The next Figure 12 shows the primary energy requirements under the resources category accounts for converted energy system requirements.

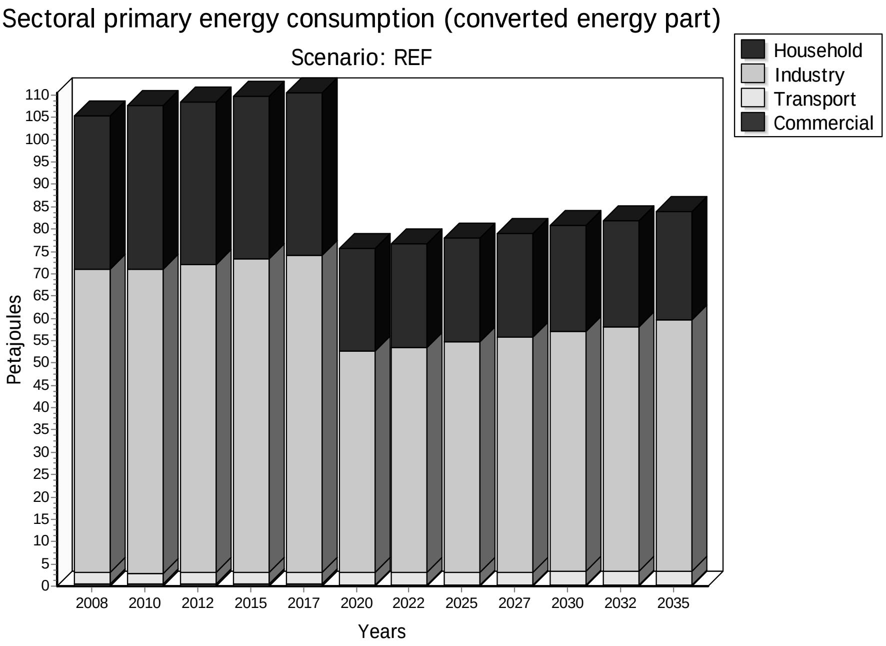

Figure 12. Sectoral primary energy demand: commercial, transport, industry and household

These primary energy requirements depend on energy production projections and decrease annually 0.76 % during the calculation period (2009-2035), taking into account the shortage of electricity production of country after year 2020 in the REF.

As shown in Figure 13 the main energy consumption areas of sectoral energy demand in the end year are mining 18 % in percent shares, urban household consumption 18 %, textile production 14 %, building and chemistry 12 %, wood production 10 %, passenger transport 7 %, food processing 7 %, other industry (including machinery, transport equipment, production of other non-metallic mineral products) 6 %, pulp and paper branch 3 %, rural household consumption 3 %, commercial heating and freight transport 2 %.

The sectoral annual growth projections over the period 2009-2035 in the REF scenario are as follows: passenger and freight transport sector increasing by 0.63 % and 1.39 % respectively; industrial wood production increasing by 1.46 %, textile production by 1.73 %, paper production by 1.45 %, mining 1.75 %, food processing 1.44 %, bilding and chemical industry by 1.45 % and other industry by 2.65 % (including machinery, transport equipment, production of other non-metallic mineral products); urban household consumption increases by 1.76 % and rural area consumption decreases by 0.84 %; commercial sector increases by 0.23 %.

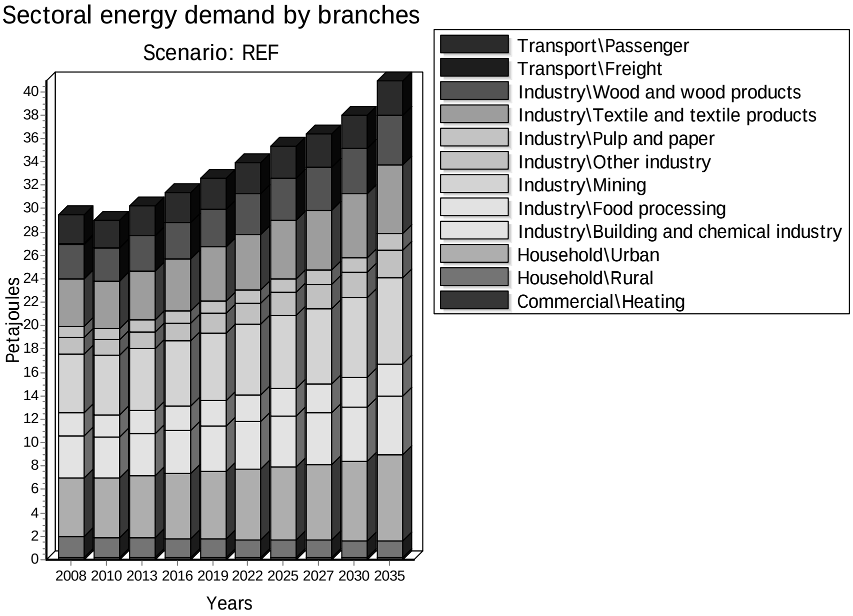

Figure 13. Sectoral energy demand by branches

The next Figure 14 shows the primary energy requirements by branches under the resources category accounts for converted energy system requirements. In the REF scenario the total primary energy consumption decreases annually 0.76% during the period 2009-2035. The sectoral annual growth projections over the period 2009-2035 in the REF scenario are as follows: passenger and freight transport sector increasing by 0.62 % and 1.39 % respectively; industrial wood production decreasing by 0.69%, textile production by 0.58 %, paper production by 0.66 %, mining 0.57 %, food processing 0.67 %, bilding and chemical industry by 0.66 % and other industry by 0.62 % (including machinery, transport equipment, production of other non-metallic mineral products); urban household consumption decreases by 0.86 % and rural area consumption by 2.0 %; commercial sector by 1.52 %.

Figure 15 also presents the fuel-wise sectoral primary energy requirements. Oil shale remains the dominant fuel as far as the sectoral energy consumption is concerned. Its consumption decreases almost 50 % after year 2020 according to energy production projections in REF scenario. The consumption of natural gas increasing after year 2012 during calculation period annually 0.6 % per year, the wood, diesel, oil and others are at the same level in the sectoral energy consumption area. The environmental loadings for technologies were calculated using the existing library of Technology and Environmental Database (TED) in LEAP model.

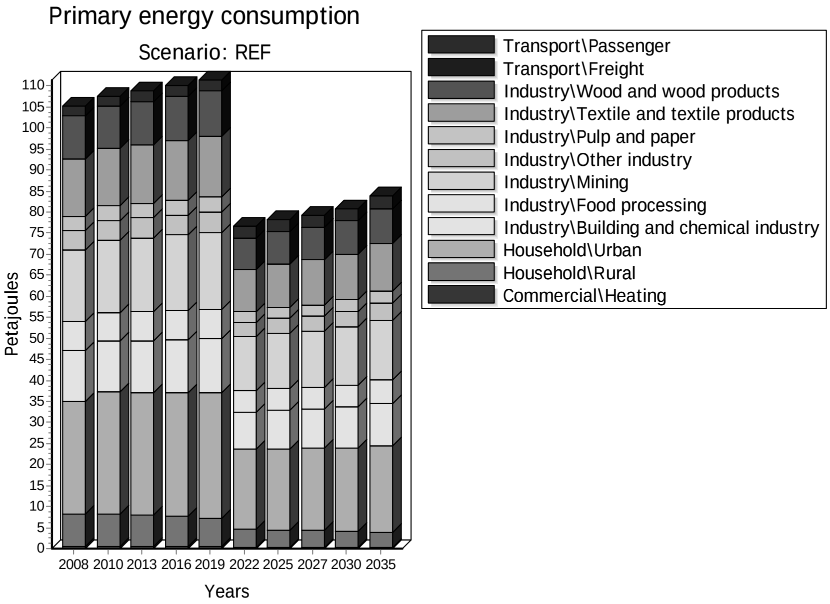

Figure 14. Sectoral primary energy consumption by branches (converted energy part)

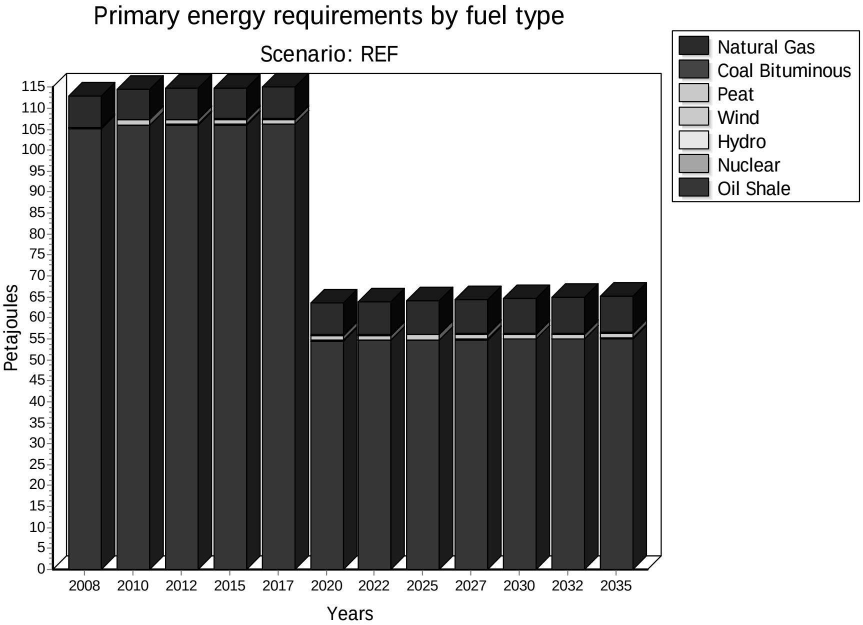

Figure 15. Primary energy requirements by fuel type

Figure 16 and 17 present fuel-wise electricity generation and electrical capacity in the REF scenario over the modelling time frame (2009-2035). The total electricity generation and electrical capacity in this scenarion is characterized that the production of electricity is dominated by oil shale; four of oil shale old units will be renovated. The penetration of various renewable energy technologies such as wind and biomass power generation is considered as per the existing situation today. The rest of oil shale old units will be closed after 2020 and only energy units nr. 8 and 11 of Narva Power Plant will be in operation. There are no new power plants in this scenario.

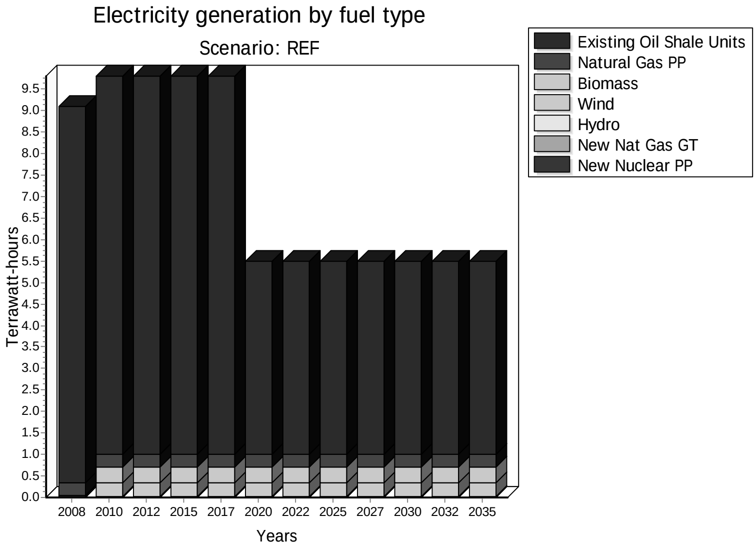

Figure 16. Electricity generation by fuel type

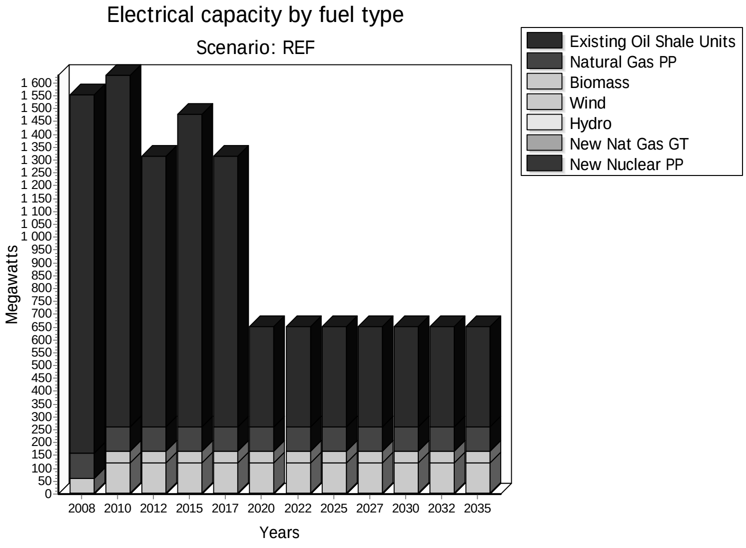

Figure 17. Electrical capacity by fuel type

In the REF scenario, the total electricity generation decreases from 9 TWh in 2008 to 5.5 TWh in 2035. The oil-shale-based generation decreases from 8.7 TWh in 2008 in the REF scenario to 4.5 TWh in the 2035. Gas-based generation has the same level as in base year because no new power plants will be built in this scenario. The growth of biomass and wind power generation is 0.36 TWh and 0.3 TWh respectively.

Figure 18 shows the trends of CO_2 emissions in million tonnes in the REF scenario over the modelling time frame. Total emission of carbon dioxide from energy production sector is calculated for two main fuels that used in the electricity generation: oil shale and natural gas, the rest of fuels are CO_2 free electricity source. The trends of amount of carbon dioxide emissions are similar to energy generation trends and have a direct correlation from using fuels in the process.

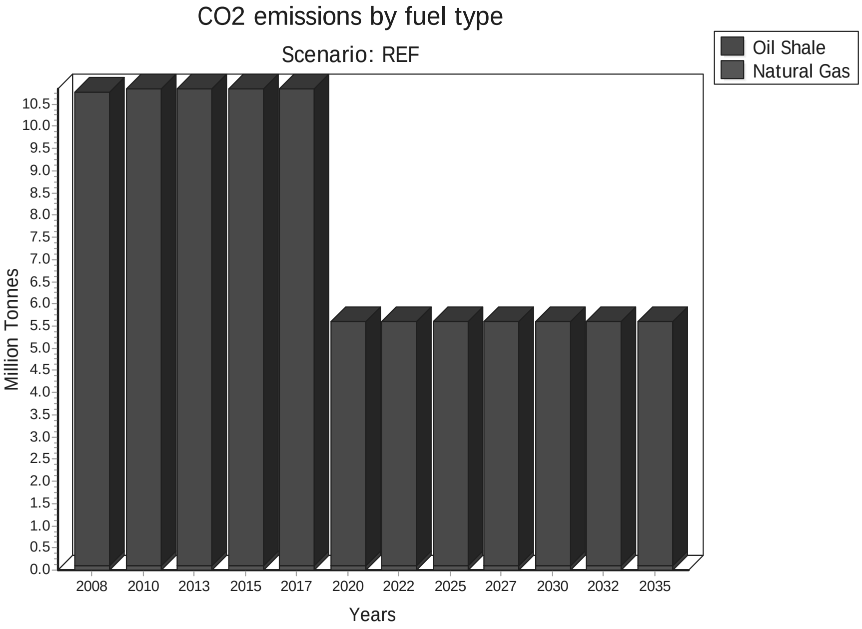

Figure 18. CO_2 emissions by fuel type

3.2.3.2 Results across various scenarios

A comparative analysis of the key results across all the scenarios is presented in this section.

Figure 19 presents the sectoral energy demand across various scenarios that include commercial, transport, industrial and residential sector. The requirements shown under the demand category shows only the primary energy required to meet domestic demands. In the REF, REN, NUC and HYB scenario, the total energy demand increases annually 1.43 % during the period 2009-2035, taking into account the economic growth projections of country in the these scenarios.

However, it increases annually by 0.7 % and 1.6 % in the LG and HG scenarios, respectively. It has been observed also that in the LHYB and HHYB scenario, the total sectoral energy demand increases the same as LG and HG scenarios.

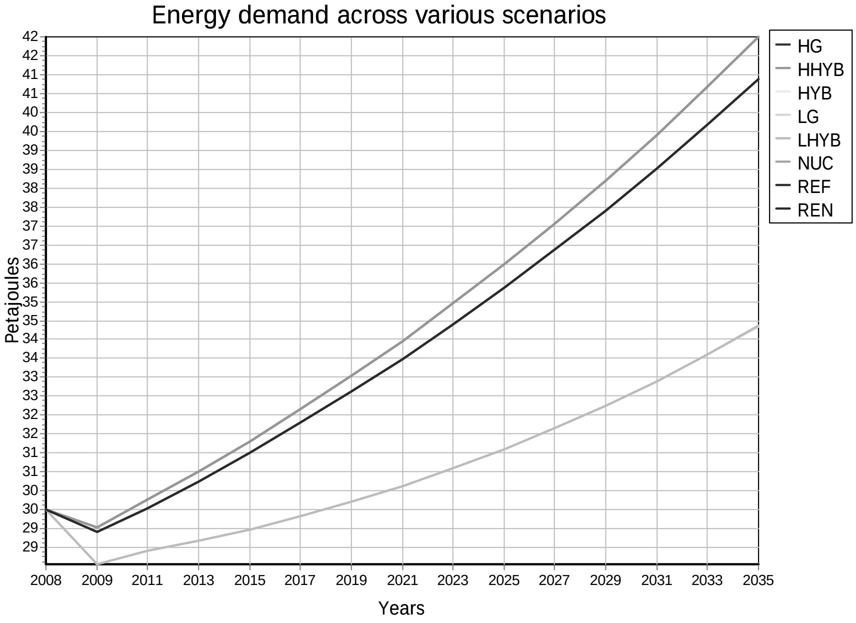

Figure 19. Energy demand across various scenarios

Figure 20 shows primary energy consumption across various scenarios, where the primary energy requirements under the resources category accounts for converted energy system requirements.

In the REF, REN, NUC scenarios the primary energy consumption decreases annually 0.76 % during the period 2009-2035, taking into account the shortage of electricity production of country after year 2020 in the REF. It decreases annually by 1.0 % in the LG and 0.72 % in HG scenarios. It also decreases annually by 0.67 % in HYB scenario, 0.92 % in the LHYB and 0.64 % in HHYB scenario.

The difference in energy consumption between the REF scenario and the HYB scenario in 2035 is 2.4 PJ (the combination of the REF, REN, and NUC scenarios and new gas turbine in the HYB scenario).

The sharp drop of primary energy consumption after year 2020 is caused by the reduction in consumption of oil shale by almost 50 % of total amount. This reduction in consumption of oil shale is attributed to the oil shale old units closing after year 2020.

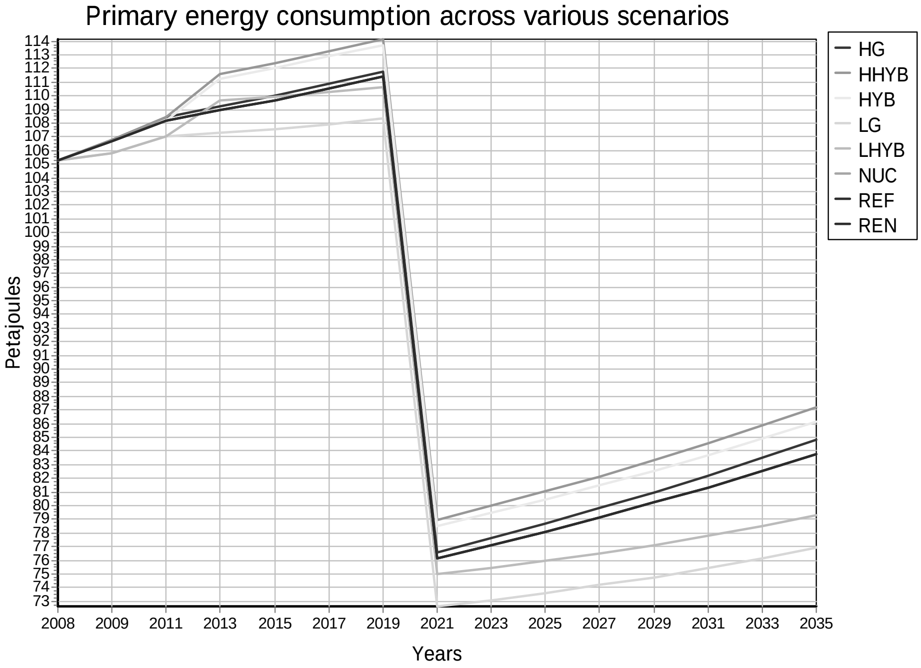

Figure 20. Primary energy consumption across various scenarios

Figure 21 presents a comparison of electricity generation across various scenarios. In the REF, LG and HG scenario, the total electricity generation decreases from 9 TWh in 2008 to 5.5 TWh in 2035, the shortage of electricity generation will be 3.6 TWh in 2035. The oil-shale-based generation decreases from 8.7 TWh in 2008 in the REF scenario to 4.5 TWh in the 2035. Gas-based generation has the same level as in base year, because no new power plants will be built in this scenario. The growth of biomass and wind power generation is 0.36 TWh and 0.3 TWh respectively.

In HYB, HHYB and LHYB scenarios, the total power generation increases from 9 TWh in 2008 to 12.7 TWh in 2035. The oil-shale, gas, biomass and wind-based energy production are the same as in the REF scenario. However, there exists variation in the technology deployment for power generation across these scenarios: it is added new nuclear and gas power generation that replaces oil-shale-based generation. In the NUC scenario, the total power generation increases by 1.4 TWh in 2035 and in the REN scenarios, the shortage of electricity generation will be 2.2 TWh in 2035.

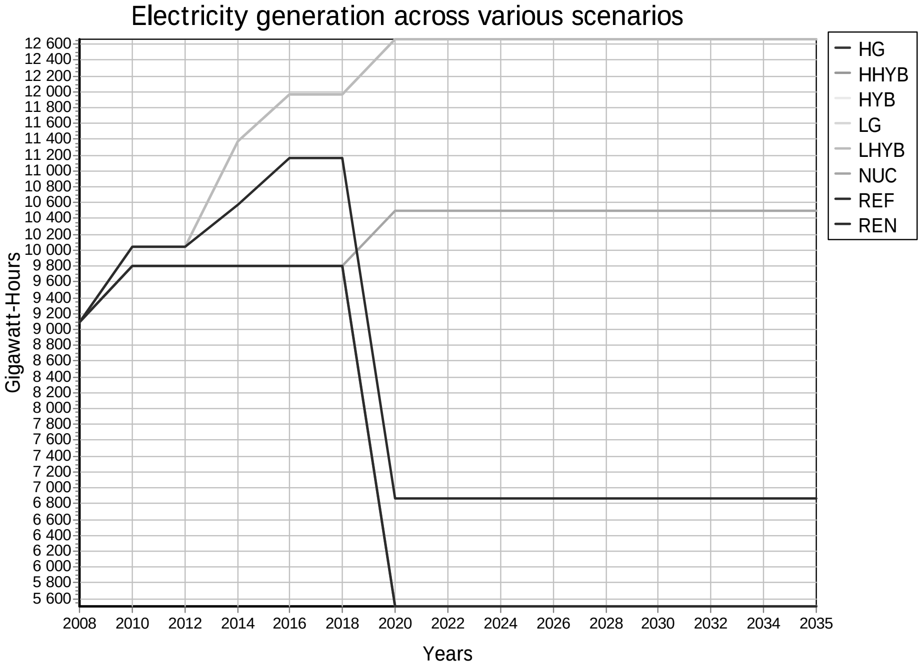

Figure 21. Electricity generation across various scenarios

Figure 22 presents a comparison of electricity generation capacity across various scenarios. In the REF, LG and HG scenario, the total electrical capacity decreases from 1 550 MW in 2008 to 650 MWh in 2035, the shortage of electricity generation capacity will be 900 MW in 2035. The oil-shale-based generation capacity decreases from 1 393 MW in 2008 in the REF scenario to 388 MW in the 2035. Gas-based generation has the same level as in base year, because no new power plants will be built in this scenario. The growth of biomass and wind power generation is 45 MW and 58 MW respectively.

In HYB, HHYB and LHYB scenarios, the total power generation increases from 1 550 MW in 2008 to 1 945 MW in 2035. The oil-shale, gas-based energy producton are the same as in the REF scenario. The biomass power capacity will increase to 138 MW and wind-based power capacity to 618 MW. The new nuclear power plant capacity of 600 MW and gas power plant capacity of 100 MW are included; there is no shortage of electricity generation capacity by 2035 in this scenario. In the NUC scenario, the total electrical capacity decreases from 1 550 MW in 2008 to 1 150 MW in 2035, the shortage of electricity generation capacity will be 300 MW in 2035 in this scenario; and in the REN scenarios, the shortage of electricity generation capacity will be 400 MW in 2035.

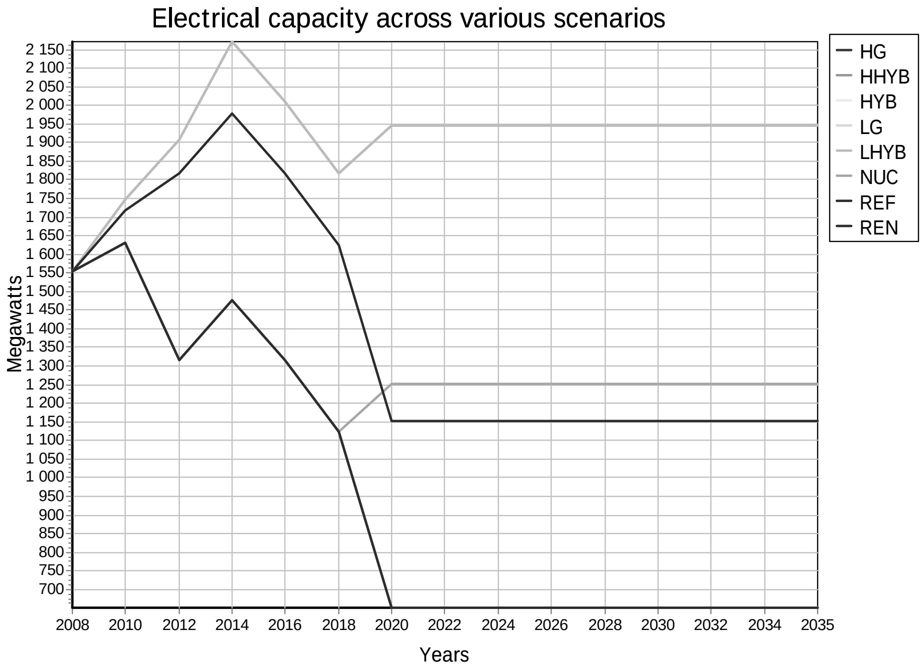

Figure 22. Electrical capacity across various scenarios

For simplifying it was shown the trends of CO_2 emissions in the REF and HYB scenarios over the modelling time frame in Figure 23. The REN, NUC, LG and HG scenarios have the same trend as in REF scenario. The HHYB, LHYB scenarios have the same total emissions of carbon dioxide as in HYB scenarios. The price level of CO_2 emissions is taken as 25 EUR/ton.

As it shown in REF and HYB scenarios the total emissions decrease sharply after year 2020 due to reduction of oil- shale-based electricity production. The HYB scenario has the advantage of new nuclear plant that does not have CO_2 emissions, however in the REF scenario about half of the electricity needed to import after the year 2020. The nuclear power plant could be politically and environmentally regarded as the preferred technology. The trends of amount of carbon dioxide emissions are similar to energy generation trends. The trends of energy generation in REF scenario are different from HYB scenario by new natural gas power plant with additional electrical capacity 100 MW.

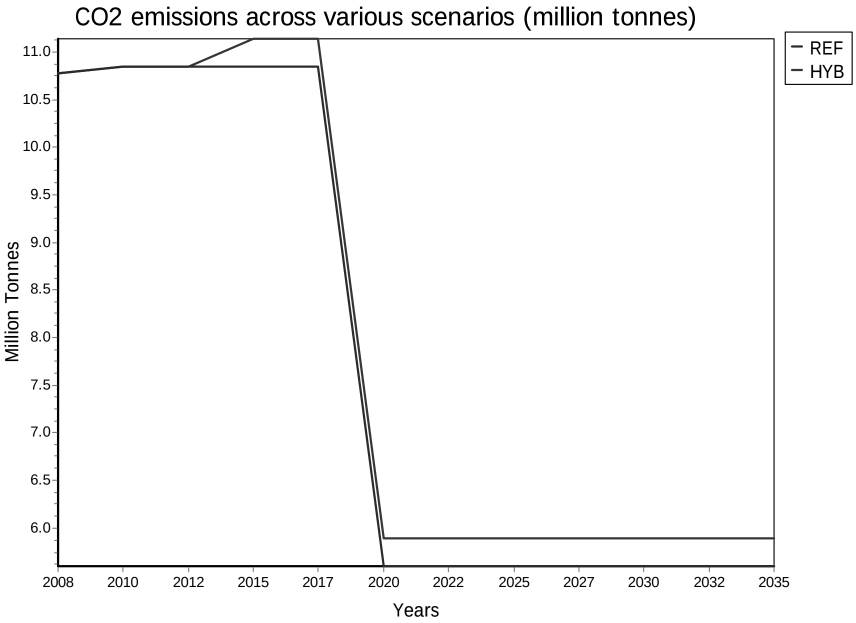

Figure 23. CO2 emissions in million tones

Figure 24 shows the energy flows modelled by LEAP. Reference Energy System (RES) diagram showing the main energy flows from resource extraction, through the conversion and transport of fuels, through to final energy demand.

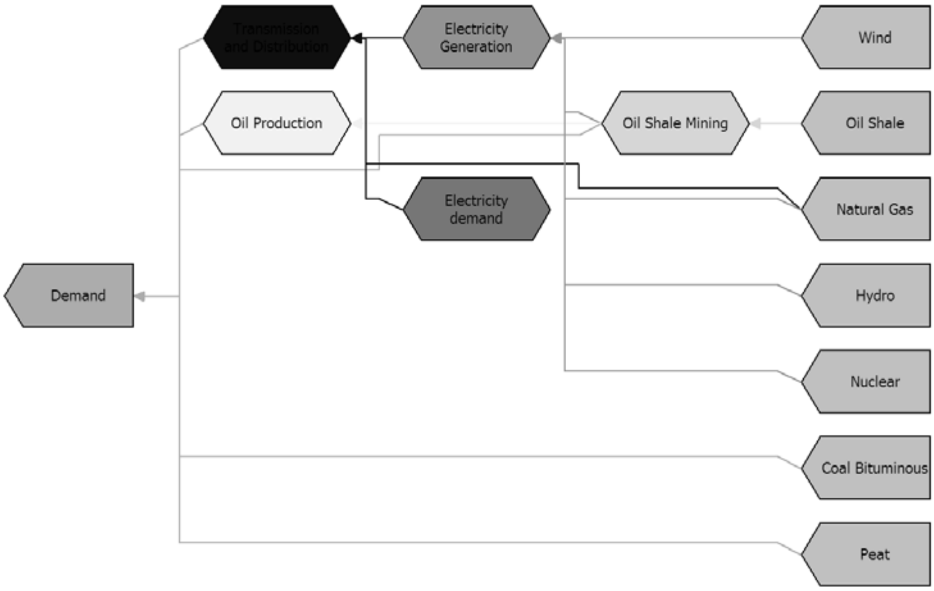

Figure 24. Simple Reference Energy System

The gray labeled nodes on the right of the RES diagram show the indigenously produced primary resources (the diagram does not currently display imports or exports). The colored nodes in the center of the diagram show the modules in transformation system, far left of the diagram is a node representing final demands. The colored lines on the RES show the individual primary input fuels to each module. They also show how secondary energy produced by each module is consumed either in another module or by final demand. Secondary fuels produced in the system are not displayed individually, but are aggregated into a single colored line. Lines on the diagram are color coded to show the modules to which they are connected [14].

CONCLUSIONS

1. For the analysis of the energy planning models, the classification and the basic distinctions of the types of models were described. During the analysis of the advantages and disadvantages of the energy planning model's main characteristics, from the point of view of the Estonian energy sector, were investigated:
    - according to the analytical approach, top-down models are the most useful for studying the broad macroeconomic and fiscal policies for mitigation of the environmental taxes, they are suitable for predictive purposes in short term; bottom-up models are suitable for studying the options that have specific sectoral and technological implications; the most flexible models are hybrid models that combine the advantages of the top-down and bottom-up models.
    - according to the methodology, the most suitable models are optimization, simulation and toolbox models; econometric and macro-economic models are less useful, because they do not represent specific technologies and no long term planning possibilities; economic equilibrium models are insufficient as the economy of the Estonian market is relatively new and changes in the structure and conditions of the economy have not fully formed.
    - concerning the mathematical approach, linear programming has a clear advantage because it allows simple programming, it can easily be understood and the problem can be solved in a straightforward way by using standard algorithms.
2. The different types of the existing energy planning models were reviewed and ten existing energy models, which have the bottom-up or hybrid approach, linear programming and according to the methodology, are simulation, optimization and toolbox models, selected for a more detailed analysis. A brief overview of the selected energy planning models, including EFOM, TIMES, LEAP, MARKAL, MESAP, MESSAGE, MIDAS, PowerPlan, RETScreen and EnergyPlan, and their application across several countries was given.
3. Most of the ten selected models are applied to the analysis of the entire energy sector as well as to the electricity and district heat single sectors. PowerPlan is applied to the analysis of the electricity supply systems only.
4. Only freely available energy planning models were selected for the analysis of the adaptability of the models: RETScreen, EnergyPlan and LEAP. The RETScreen and EnergyPlan models were used in the calculations of the heat energy supply alternatives modelling in Narva city. The LEAP model was used for the elaboration of the scenarios of the Estonian energy system's development.

5. The analysis of the heat energy supply alternatives modelling in Narva city was given to compare the oil shale condensing extraction turbine block usage with biomass CHP, natural gas CHP and boiler house economy. Both of the models (RETScreen, EnergyPlan) could be equally used for the pre-feasibility study of the new capacity planning projects. The results of the reviewed models are marginally different; the models are indicative for the scenarios development and could be useful for comparing the fundamental technological processes.
6. The advantage of using these models is that they allow to get reliable results by using comparatively low input data. The RETScreen energy model has more detailed input requirements of technological characteristics for the new energy capacity planning and the EnergyPlan model is more suitable for the whole country's energy balance planning.
7. The disadvantage of the EnergyPlan model is that it does not have opportunities to calculate the financial feasibility indicators and payback of the projects when modelling the new capacities.
8. Compared to the LEAP model, neither of the models (RETScreen, EnergyPlan) have the possibilities for inputting the external assumption information and data of the sectors such as industry, mining, commercial and residential.
9. The analysis based on the LEAP model was done across the eight scenarios of the development of the Estonian energy system during the period 2009-2035, and key results across all the scenarios were given. Estonian energy system was simplified with a transparent structure and an overview of the current energy supply in Estonia, future changes and projections of the Estonian energy production system related to the restrictions in technology and environment were given.
10. The LEAP model, a user-friendly and freely available tool, demonstrated the usage of the model’s features in connection with the Estonian electricity system and it could be suitable for elaborating the scenarios for the whole energy sector and for electricity and heat single sectors, including external assumptions. Afterwards, the model may serve as a basis for a more accurate model of Estonia, and the data presented in this work will be helpful for the energy planners, researchers and analysts.
11. Based on the practical part of this work, it could be concluded that the methodological approach of the selection of energy planning models was substantiated and the selected models are suitable for the analysis of the energy sector in Estonia.

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ENERGY PLANNING MODELS ANALYSIS AND THEIR ADAPTABILITY FOR ESTONIAN ENERGY SECTOR

ABSTRACT

The trend of liberalization and changes in the Estonian energy market, related to the European Union's strict technological and environmental requirements, give rise to the need to develop the modeling of new scenarios for the energy sector in Estonia by mitigating the environmental impacts of electricity production and using new, less environment-damaging technology. The easiest way to develop scenarios is to use energy planning modeling.

Modeling is one of the complicated forecasting methods. In recent years, a large number of energy planning models have been developed. Energy planning models often become useful when analyzing complex systems involve a lot of data; they help to understand the relationships between the different parameters and work out development scenarios in any country. Afterwards, the model may serve as a basis for a more accurate model of the country.

Objectives of the thesis are analysis and evaluation of the existing energy models in the world; development of the selection criteria and selection of the several energy models for the analysis of the energy market in Estonia; practical testing of the applicability of the selected models to Estonia.

Only freely available energy planning models were selected for the analysis of the adaptability of the models: RETScreen, EnergyPlan and LEAP. The RETScreen and EnergyPlan models were used in the calculations of the heat energy supply alternatives modelling in Narva city. The LEAP model was used for the elaboration of the scenarios of the Estonian energy system's development. An overview of the current energy supply in Estonia and future changes of the Estonian energy production system related to the restrictions in technology and environment was given. The classification of the energy system models and their basic structure were provided.

The methodological approach of the selection of the energy planning models was substantiated and the selected models are suitable for the analysis of the energy sector in Estonia. The present work will be helpful for the energy planners, researchers and analysts.

Keywords: energy planning, energy model, optimization, simulation, toolbox, reference energy system, LEAP, EnergyPlan, RETScreen.

ENERGEETIKA PLANEERIMISE MUDELITE ANALÜÜS JA NENDE RAKENDATAVUS EESTI ENERGIASEKTORIS

KOKKUVÕTE

Eesti on väike riik, kus elektrienergia tootmine, põlevkivi kaevandamine ja töötlemine on regionaalne majanduslik kompleks koos oma raskustega. Eestis toodetakse siiani üle 90% elektrienergiast põlevkivijaamades. Eesti energiasüsteemi struktuur on välja arendatud lähtudes elektritootmisest Narvas, kuid see ei vasta enam Eesti Vabariigi vajadustele seoses muutustega, mis tulenevad keskkonnanõuetest, energiaturu avanemisest, energiatootmise hajutamisest, taastuvenergia kasutuselevõtust ja koostootmise laienemisest. Elektritootmise planeerimist ei saa vaadelda üldisest majandusarengust ja üldenergeetikast lahutatult. Seetõttu peaksid energiasüsteemi tehtavad investeeringud olema suunatud süsteemi muutmisele nii Eestis kui ka teistes Euroopa Liidu maades, mis soodustaksid igati edukat majandusarengut. Balti riikide ees on praegu keerukas olukord, kus peab loobuma monopolist ja arendama vaba elektriturgu vastavalt Euroopa Liidu nõuetele. Eesti on aga taotlenud üleminekuperioodi põlevkivi baasil toodetava energia arengu lahendamiseks. Liberaliseerimise trendid ja muutused Eesti energiaturul on seotud Euroopa Liidu tehnoloogia ja keskkonna rangete nõuetega. Selle tõttu tekib vajadus arendada uusi Eesti energiasektori stsenaariume. Arvestada tuleb keskkonnamõjusid elektrienergia tootmisel ning kasutusse tuleb võtta uusi keskkonnaohutuid tehnoloogiaid. Arengu planeerimisel tuleb arvestada võimalikke tehnoloogilisi uuendusi planeerimisperioodil (uued generaatorid, nt. gaasiturbiinid, kohalike väiketootjate lisandumine), energia (soojuse ja elektri) tariifimäärade muutusi, seadmete ja materjalide arengut. Lihtsaim meetod nende stsenaariumide arendamiseks on energeetika planeerimise modelleerimise kasutamine.

Modelleerimine on üks keerulisemaid planeerimise meetodeid. Viimastel aastatel on välja arenenud suur hulk energeetika planeerimise mudeleid. Energeetika planeerimise mudelite kasulikkus ilmneb, kui analüüsitakse paljude andmetega keerukaid süsteeme. Mudelid aitavad mõista seoseid erinevate parameetrite vahel ja töötada välja stsenaariumeid arenguks igas riigis. Saavutatud mudel võib saada aluseks täpsema mudeli jaoks.

Käesoleva doktoritöö eesmärgid on järgmised:

1. maailmas toimivate energeetikamudelite analüüs ja hinnang;
2. valikukriteeriumite väljatöötamine ja energeetika planeerimise mudelite valik Eesti energiaturu analüüsiks;
3. valitud energeetika planeerimise mudelite praktiline rakendatavus Eesti jaoks.

Esimeses peatükis on antud ülevaade praegusest energiavarustusest Eestis ja tulevastest muutustest Eesti energiatootmise süsteemis seoses tehnoloogia ja keskkonna piirangutega.

Teine peatükk käsitleb energeetika planeerimise mudelite klassifiktsiooni ning mudelite põhistruktuuri. Samuti on seal välja töötatud energeetika planeerimise valikukriteeriumid ning nende kriteeriumide alusel on valitud välja mudelid edasiseks analüüsiks. Valitud mudelitest on antud lühiülevaade koos näidetega nende rakendamisest erinevates riikides.

Kolmas peatükk on pühendatud energeetika planeerimise mudelite praktilise rakendatavuse uurimisele. Uuring on jagatud kahte ossa. Esimeses osas on testitud kahte mudelit RETScreen ja EnergyPlan eesmärgiga soojuse energiavarustuse alternatiivide modelleerimiseks Narva linnas. Teises osas on välja töötatud kaheksa stsenaariumi Eesti energiasüsteemi arendamiseks LEAP mudeli abil perioodiks 2009-2035, võttes arvesse peamisi kohustusi ja arengutrende elektrienergia sektoris kuni aastani 2020.

Kokkuvõtteks:

1. On analüüsitud energeetika planeerimise mudelite klassifikatsiooni ja kirjeldatud põhilisi liike. Energeetika planeerimise mudelite karakteristikute eeliste ja puuduste analüüsimise käigus, pidades silmas Eesti energiamajandust, jõuti järgmiste järeldusteni:
    - Vastavalt analüütilisele lähenemisele on ülalt-alla mudelid kasulikumad makromajanduse ja keskkonnamaksude uurimiseks. Nad sobivad ennustamiseks eesmärgiks lühikeseks ajaperioodiks. Alt üles mudelid sobivad konkreetsetes valdkondades erinevate tehnoloogiliste mõjude uurimiseks. Kõige paindlikumad mudelid on hübriidsed mudelid. Nendes on kombineeritud ülalt-alla ja alt-üles mudelite parimad näitajad.
    - Vastavalt metoodikale on kõige sobivamad mudelid optimeerimise, simulatsiooni ja töövahendite mudelid. Ökonomeetrilise ja makromajanduse mudelid on vähem kasulikud, sest nad ei esinda kindlaid tehnoloogiaid ega pikaajalise planeerimise võimalusi. Majandusliku tasakaalu mudelid on aga ebapiisavad, sest Eesti turg on majanduslikus mõttes suhteliselt uus ja on lõplikult veel välja arenemata.
    - Vastavalt matemaatilisele lähenemisele on lineaarsel programmeerimisel selge eelis, sest see võimaldab lihtsa programmeerimise, toob esile probleemi ja aitab seda lahendada lihtsalt viisil, kasutades standardseid algoritme.
2. Erinevate olemasolevate energeetika planeerimise mudelite läbivaatamisel valiti välja kümme olemasoleva energeetika mudelit, mis omavad alt-üles või hübriidse lähenemise, lineaarse programmeerimise ja vastavalt metoodikale on optimeerimise, simulatsiooni ja töövahendite mudelid. Tehtud on lühiülevaade valitud energeetika planeerimise mudelitest EFOM, TIMES, LEAP, MARKAL, MESAP, MESSAGE, MIDAS, PowerPlan, RETScreen, EnergyPlan ja nende rakendamisest erinevates riikides.
3. Enamik valitud mudeleid modelleerib kogu energiasektori, samuti võimaldades eraldi modelleerida ka elektri ja kaugkütte sektori. PowerPlan mudelit kasutatakse ainult elektrivarustussüsteemide analüüsiks.

4. Rakendatavuse analüüsimiseks on valitud ainult vabalt kättesaadavad energeetika planeerimise mudelid: RETScreen, EnergyPlan ja LEAP. RETScreen ja EnergyPlan. RETScreen ja EnergyPlan mudeleid kasutati soojuse energiavarustuse alternatiivide modelleerimisel Narva linnas. LEAP mudelit on kasutatud Eesti energiasüsteemi arendamisel.
5. Soojuseenergiaga varustamise alternatiivide modelleerimise analüüsimisel Narva linnas võrreldi ökonoomsust põlevkivi vaheltvõttu turbiiniga ploki, biomassi CHP, maagaasi CHP ja katlamaja vahel. Mõlemad mudelid (RETScreen, EnergyPlan) võivad olla kasutusel ennetavates uuringutes uute tootmisvõimsuste planeerimise projektides. Vaadeldud mudelite tulemused on aga marginaalselt erinevad: antud mudelid sobivad stsenaariumide arendamiseks ning põhiliste tehnoloogiliste protsesside võrdlemiseks.
6. Eeliseks on see, et need võimaldavad saada usaldusväärseid tulemusi väheste lähteandmetega. RETScreen mudel vajab tehnoloogiliste karakteristikute detailsemaid lähteandmeid uute energiatehnoloogiate ehitamise planeerimisel. EnergyPlan mudel sobib rohkem terve riigi energiabilansi planeerimiseks.
7. EnergyPlan mudeli puuduseks on see, et ei ole võimalik arvutada finantsilisi näitajaid ja tasuvusaega uute projektide modelleerimisel.
8. Erinevalt LEAP mudelist puudub mudelitel RETScreen ja EnergyPlan võimalus sisestada parameetreid ja lähteandmeid erinevate valdkondade kohta. Näiteks andmeid tööstuse, mäetööstuse, äri ja elamute kohta.
9. LEAP mudeli analüüsi põhjal on tehtud üle kaheksa stsenaariumi Eesti energiasüsteemi arendamiseks perioodil 2009-2035 a. Tulemused kõigi stsenaariumide kohta saavutati. Eesti energiasüsteemi on lihtsustatud läbipaistva struktuuriga ja antud ülevaade praegusest energiavarustusest Eestis, tulevatest muutustest ja prognoosidest Eesti energiatootmise süsteemis seoses tehnoloogia ja keskkonna piirangutega.
10. LEAP mudel on kasutajasõbralik ning vabalt kättesaadav vahend, mida võib kasutada Eesti energiasüsteemi stsenaariumide väljatöötamisel kogu energiasektoris ning elektri ja soojuse sektorites pikemaajaliste plaanide koostamisel. Töös esitatud andmed ja tulemused on vajalikud energeetika arengu planeerijatele, teadlastele ja analüütikutele.
11. Käesoleva töö praktikalise osa põhjal võib järeldada, et energeetika planeerimise mudelite valikul metoodiline lähenemine on põhjendatud ning valitud mudelid sobivad Eesti energiasektori analüüsimiseks.

Appendix A
ORIGINAL PUBLICATIONS

PAPER I

Dementjeva N., Siirde A. Analysis of energy models and their adaptability for Estonian energy market. Power Engineering, 2009, No. 2, pp. 107-115.

ENERGETIKA. 2009. T. 55. Nr. 2. P. 107–115

Analysis of energy models and their adaptability for Estonian energy market

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In recent years, a large number of models have been developed for energy system analysis including demand and supply forecasts and impacts of policy shifts on overall energy systems. Energy models are based on different fundamental approaches and concepts, and employ a range of mathematical algorithms. As a consequence, these models vary considerably, and the question arises which model is most suited for a certain purpose or situation.

Estonia is the only country in Europe that has a significant oil-shale mining industry, and 95% of Estonian electricity is produced by oil-shale power plants. The Baltic countries are facing a complex situation in breaking up the monopoly and solving the free electricity market issues. Also, Estonia has applied (for a transition period) for the oil shale-based energy sector development. The trend of liberalization and changes in the Estonian energy market, related to European Union strict technological and environmental requirements, needs developing new scenarios for the energy sector in Estonia to mitigate the environmental impacts of electricity production by using new, less environment-damaging technologies. This paper presents an ongoing research project where the objective is to analyse energy planning models to elaborate scenarios of developing the Estonian energy system in the conditions of oil shale-based electricity supply shortage, taking into account the main engagements and figures of the electricity sector by year 2015.

Key words: energy planning, modeling, energy model, supply, demand, forecast, optimization, economic equilibrium, simulation

1. INTRODUCTION

Energy models were first developed in the 1970s because of the increasing availability and development of computers and the increasing environmental awareness. Most of the energy models were built and used in industrialised countries, so that the main assumptions about energy systems were mainly based on the experience from these countries. Energy models are based on different fundamental approaches and concepts, and employ a range of mathematical algorithms. As a consequence, these models vary considerably, and the question arises which model is most suited for a certain purpose or situation.

In order to decide which model is better to use, it is important to know the model characteristics, structures, data and modelling methods. The ways of classification are given in this work and the basic distinctions of the types of models such as econometric, macro-economic, economic equilibrium, optimization, simulation, spreadsheet / toolbox and backcasting are described. In practice, it is not feasible to develop our own models for energy planning; it is more effective to use existing models, but the key question is to decide which model should be used. The purpose of this paper is to give information about user-friendly tools for energy planning analysts to perform demand and supply analysis and to elaborate the methodology of planning and forecast. For comparison, we selected and compared different worldwide used energy-planning models.

2. CLASSIFICATION OF ENERGY SYSTEM MODELS

Models are built for various purposes and consequently have different characteristics and applications.

Nine ways of their classification are presented:

1. Purposes of energy models:
   - General: forecasting, exploring, backcasting.
   - Specific: energy demand, energy supply, impacts, appraisal, integrated approach, modular build-up.
2. The model structure: internal assumptions and external assumptions.
3. The analytical approach: top-down, bottom-up and hybrid.
4. The underlying methodology: econometric, macro-economic, economic equilibrium, optimization, simulation, spreadsheet / toolbox and backcasting.
5. The mathematical approach: linear programming, mixed-integer programming, dynamic programming.
6. Geographical coverage: global, regional, national, local, or project.
7. Sectoral coverage: single-sectoral models and multi-sectoral models.
8. The time horizon.
9. Data requirements.

Such classification of energy models is helpful for understanding their need, their roles and their specificity in relation to the studies under consideration [1].

Table 1. **Characteristics of top-down and bottom-up models**

Top-down models	Bottom-up models
Use an "economic approach"	Use an "engineering approach"
Give pessimistic estimates on "best" performance	Give optimistic estimates on "best" performance
Cannot explicitly represent technologies	Allow for a detailed description of technologies
Reflect available technologies adopted by the market	Reflect the technical potential
The "most efficient" technologies are given by the production frontier (which is set by market behaviour)	Efficient technologies can lie beyond the economic production frontier suggested by market behaviour
Use aggregated data for predicting purposes	Use disaggregated data for exploring purposes
Are based on actual market behaviour	Are independent of the actual market behaviour
Disregard the technically most efficient technologies, thus underestimate the potential for efficiency improvements	Disregard market thresholds (hidden costs and other constraints), thus overestimate the potential for efficiency improvements
Determine energy demand through aggregate economic indices (GNP, price elasticities), but vary in addressing energy supply	Represent supply technologies in detail, using disaggregated data, but vary in addressing energy consumption
Endogenize behavioural relationships	Assess costs of technological options directly
Assumes obsence of discontinuities in historical trends	Assumes that the interaction between energy sector and other sectors is negligible

Generally, recent models offer an integrated approach in the sense that they combine several specific purposes, although some of the models focus on one aspect only (such as some utility expansion or environmental impact models). Beside the purpose, models can also be distinguished according to their structure:

- Internal assumptions: degree of endogenization, description of non-energy sectors, description of end-uses, and description of supply technologies.
- External assumptions: population growth, economic growth, energy demand, energy supply, price and income elasticities of energy demand, existing tax system and tax recycling.

Concerning the mathematical approach, linear programming has a clear advantage in that it allows for simple programming and can easily be understood by planners because no special expertise is needed. In this case, the problem can be solved in a straightforward way by using standard algorithms.

The geographical coverage reflects the level at which the analysis takes place: the global models describe the world economy or situation; the regional level frequently refers to international regions; the national models cover all major sectors in a country, taking into account world market conditions; the local models refer the regions within a country, and the project level is a somewhat special case.

By the sectoral coverage, a model can be focused on only one sector or include more sectors.

The time horizon models are divided into:

- Short-term (5 years or less)
- Medium-term (5–15 years)
- Long-term (10 years or more).

Finally, by the data requirement, a model can require certain types of data: qualitative, quantitative, monetary, aggregated and disaggregated.

We will discuss in more detail the analytical approach and the underlying methodology in the next two sections.

2.1. The analytical approach to energy system models

In the analytical approach, the models can be divided into top-down, bottom-up and hybrid. The distinction between top-down and bottom-up models is particularly interesting because they tend to produce opposite outcomes for the same problem. In top-down models, the functional details of the system are derived from aggregated macro-economic parameters, such as labour, capital, interest rate, etc. In contrast, in bottom-up models the driver is energy service demand, and the results are produced by the structure of the detailed technology system. The bottom-up model is thus rich in technological details, and aggregated values are based on the projection of energy service demand and the properties of these technologies.

The top-down and bottom-up models can be combined in a hybrid approach, depending on the purpose, data requirements and desired output [1].

The different aspects related to the top-down and bottom-up models are summarized in Table 1.

Top-down models are most useful for studying broad macroeconomic and fiscal policies such as carbon or other environmental taxes. Top-down models externalise major structural changes such as lifestyles, urbanisation and technological changes. The strengths of the top-down approach are its consistency, links to historic references and economic frameworks, equilibrating prices and quantities, and its data availability.

Bottom-up models are most useful for studying options that have specific sectoral and technological implications. The bottom-up approach can be useful mainly because the model is independent of market behaviour and production frontiers and because technologies are explicitly modelled. The weaknesses of bottom-up models are that their main drivers such as demand, technology change and resources remain exogenous [1].

The hybrid approach leads to flexible models, because it combines the advantages of top-down and bottom-up models. Both top-down and bottom-up models can be useful for certain purposes of future forecasts, but most of energy planning models are focused on bottom-up or hybrid approaches because of their flexibility.

2.2. The underlying methodology of energy system models

Concerning the underlying methodology there are eight types of models: econometric, macro-economic, economic equilibrium, optimization, simulation, spreadsheet / toolbox and backcasting. In practice, the distinction is not always clear. The literature makes a distinction between simulation, optimization, and spreadsheet methods usually only when referring to bottom-up models, while recent economic top-down models use optimization and simulation techniques as well. On the other hand, econometric, macro-economic, and economic equilibrium methods are generally applied only in top-down models, although there are also some exceptions.

I. Econometric models

Econometric methodologies are methodologies that apply statistical methods to extrapolate past market behaviour into the future. Nowadays econometric methodologies are mainly used as parts of macro-economic models. A disadvantage of this methodology is that it does not represent specific technologies at all and could not be use for long-term planning.

II. Macro-economic models

The macro-economic methodology focuses on the entire economy of a society and on the interaction between the sectors and well known as input-output models. Input-output tables are used to describe transactions among economic sectors and assist in analysis of energy-economy interactions in short-term planning. Input-output models are often developed for exploring purposes, using assumed parameter and scenarios that do not necessarily have to reflect reality.

Similar to the econometric methodology, the macro-economic methodology has the disadvantage that it does not represent specific technologies.

III. Economic equilibrium models

Economic equilibrium methodologies are mainly used to study the medium and long-term energy sector as part of the overall economy and focus on interrelations between the energy sector and the rest of the economy. Economic equilibrium models are sometimes also referred to as resource allocation models. Some energy-economic models consider energy price equilibrium while balancing supply and demand. Price equilibrium energy-economic models can further be divided into two categories: partial and general equilibrium models. Partial equilibrium models only focus on equilibria in parts of the economy, such as the equilibrium between energy demand and supply. General equilibrium models consider simultaneously all the markets in an economy, allowing for feedback effects between individual markets.

IV. Optimization models

Optimisation models are used to optimise energy investment decisions by finding best solutions. Optimisation models assume perfect markets and optimal consumer behaviour that do not exist in real life. Utilities or municipalities to derive their optimal investment strategies often use optimization. Furthermore, in national energy planning, it is used for analyzing the future of an energy system. Underlying assumption of optimization methodologies is that all acting agents behave optimal under given constraints. Disadvantages are that optimization models require a relatively high level of mathematical knowledge and that the included processes must be analytically defined. Optimization models often use linear programming techniques.

V. Simulation models

Simulation models are descriptive models based on a logical representation of a system, and they are aimed at reproducing a simplified operation of this system. Simulation models are a "what if" tool, they calculate what would happen under given assumptions of consumption forecasts and policies. Such models, however, allow the users to explore different hypotheses via scenarios, and typically capture the area of interest at a macro-economic level. These models are used to investigate technologically oriented measures where macro-economic interactions, i. e. price effects are less important.

Simulation models are especially helpful in cases where it is impossible or extremely costly to do experiments on the system itself. They are often used in scenario analysis.

VI. Spreadsheet models (tool boxes)

In the literature the spreadsheet methodology is often mentioned as a separate (bottom-up) methodology. Although the models all make use of spreadsheets (as the term suggests), this term may cause some confusion because other methodologies also frequently use spreadsheet programs as a basis. Spreadsheet models are as "tool boxes" which often include a reference model that can easily be modified according to individual needs.

VII. Backcasting models

The backcasting methodology is used to construct visions of desired futures by interviewing experts in the fields and subsequently by looking at which trends are required or need to be broken to accomplish such futures. This approach is often used in alternative energy studies [1].

3. CURRENT SITUATION IN ESTONIAN ENERGY

Estonia is a small country where electricity production, mining and processing of oil shale is a regional economic complex with their difficulties. Estonia is facing a complex situation in breaking up the monopoly and developing a free electricity market. The strategic objective of the Estonian electricity sector development plan until 2015 is to assure the optimal functioning and development of the Estonian power system in the market economy conditions and to assure in the long-term outlook the proper supply of electricity to the consumers at a lowest price possible, at the same time implementing all reliability and environmental conditions. The main engagements and figures of the electricity sector by year 2015 are followed:

- to achieve 5.1% of electricity production from renewable energy resources in 2010;
- to achieve 20% of electricity production from electricity and heat co-generation in 2020;
- to open the Estonian electricity market for 35% in 2009 and for all consumers in 2013.

Today, the Estonian electricity market is open for 13 eligible customers whose annual consumption is about 16% of energy in Estonia. Non-eligible customers can purchase electricity from the grid company they are physically connected to or from the seller named by that grid company. At present, the electricity production from renewable energy resources is about 1.5% and

Table 2. **Energy model characteristics**

	Macro-economic models	Energy equilibrium models	Optimization models	Simulation models	Spreadsheet models
Timeframe	Short to medium-term	Medium to long-term	Short to long-term	Short to long-term	Medium to long-term
Level of detail	High	Low	High	Partially high	Technically specific
System boundaries	Entire economy	Entire economy	Energy system	Energy system	Entire economy
Flexibility in terms of technically detailed questions	Low	Low	High, dependent upon the level of detail of the tech. database	High for limited complexity	High
Theoretical foundation	Historical analysis of macro-economic interaction matrix	Neo-classical	Optimization with regard to tech.-economic criteria	Primarily tech. determinism of energy systems	Primarily tech. determinism of energy systems
Implementation of the modeling	Econometric estimation of the interconnections of the matrix	Decisions corresponding to nesting and elasticities	Technological database with optimization algorithms	Technological database, expert knowledge	Technological database
Strengths	Broad empirical foundation, sectoral disaggregation	Closed theoretical structure	Applicable to tech. total sys. Flexible application possibilities	Also usable without targeted entities for optimization	Applicable to tech.systems. Flexible application possibilities
Weaknesses	Does not represent specific technologies. No long-term planning	Small empirical basis, often low level of sectoral differentiation	Implicitly rational optimization decisions, strongly influenced by bounds	Economic influences underrepresented, based considerably on the quality of expert knowledge	For local applicability. Variables are indicated exogenously as parameters in future scenarios

Table 3. **Energy planning models and their grouping in the analytical approach**

	Models	Top-down	Bottom-up	Hybrid
1	AIM (Asian-Pacific Integrated Model)			X
2	BRUS (Brundtland Scenario)		X	
3	EFOM (Energy Flow Optimization Model)		X	
4	ENPEP (Energy and Power Evaluation Program)		X	
5	GEM-E3 (General equilibrium model)	X		
6	IMAGE / TIMER (TARGETS-IMAGE Energy Regional Model)			X
7	LEAP (Long-range Energy Alternatives Planning)		X	
8	MARIA (Multiregional Approach for Resources and Industry Allocation model)	X		
9	MARKAL (MARket ALLocation)		X	
10	MARKAL-MACRO (A simplified energy-economy model)			X
11	MEGEVE-E3ME (General energy–environment–economy mode)	X		
12	MERGE (Model for Evaluating Regional and Global Effects of GHG Reductions Policies)			X
13	MESAP (Modular Energy System Analysis and Planning software)			X
14	MESSAGE III (Model for Energy Supply Systems Analysis and General Environment)		X	
15	MIDAS (Multinational Integrated Demand and Supply)			X
16	MiniCAM (Mini Climate Assessment Model)			X
17	MURE / ODYSSEE (Measures d'Utilisation Rationelle de l'Energie)		X	
18	NEMS (National Energy Modelling System)			X
19	POLES (Prospective Outlook on Long-term Energy Systems)		X	
20	PowerPlan (Interactive simulation model)		X	
21	PRIMES (Partial equilibrium model)			X
22	RETScreen (Renewable Energy Technology Screening)		X	
23	SGM (Second Generation Model)	X		
24	WEM (World Energy Model)			X

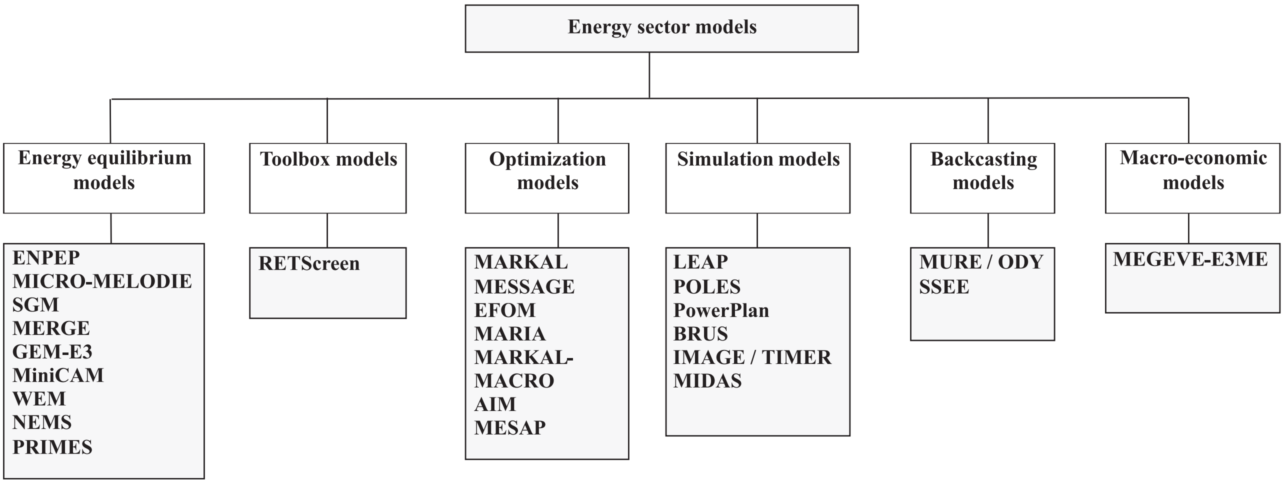

Fig. 1. Energy planning models and their grouping methodology

the electricity production from electricity and heat co-generation is about 7% of gross consumption.

So, the major investments in electricity production will be:

- peat and biomass CHP-s with the gross capacity of 100 MW in 2010–2015;
- wind turbines with the gross capacity of 200 MW by the year 2015;
- the first oil shale CFBC unit with the gross capacity of 270 MW in 2015;
- the second oil shale CFBC unit with the gross capacity of 270 MW in 2016 [2].

4. THE MAIN CHARACTERISTICS AND COMPARISON OF THE MODELS

As described above, there are several types of models based on different fundamental approaches and concepts.

Table 2 summarizes the main characteristics of energy modelling approaches, including macro-economic, energy equilibrium, optimization, simulation and spreadsheet models [3].

Macro-economic models are less useful because they extrapolate the past market behaviour into the future, do not represent specific technologies and long-term planning possibilities. The economic equilibrium models are insufficient because the Estonian market economics is relatively new, and changes in the structure and conditions of its economy are not yet fully formed.

The optimisation models can be useful for Estonia to optimise energy investment decisions by finding best solutions. The assumption of perfect markets and optimal consumer behaviour is suitable for Estonia because a large part of its population reflect consumer behaviour, have access to modern energy, and the economy is market-based.

Another option is simulation models which mostly bottom-up, or hybrid descriptive models which aim at reproducing a simplified task of a system. They tend to be rather useful for Estonia, because they do neither assume perfect markets nor optimal consumer behaviour, but allow scenario analysis for future pathways.

Finally, toolbox models which are mainly bottom-up accounting type models, having the advantage that they are easy to use, which increases their usefulness for Estonia where users do often not have the same financial and training possibilities as in the other countries. The main disadvantage of toolbox models is that all important variables are indicated exogenously as parameters in future scenarios.

Backcasting models are less useful for this country.

Concerning the mathematical approach, linear programming has a clear advantage in that it allows for simple programming and can easily be understood by planners because no special expertise is needed. In this case the problem can be solved in a straightforward way by using standard algorithms.

In practice, it is not feasible to develop our own models of energy planning; it is more effective to use existing models. Energy sector models that are widely used across several countries for carrying out their economic and energy sector planning are presented in Table 3 and grouped in an analytical approach (top-down, bottom-up, hybrid).

4.1. The overview of existing energy models

EFOM comprises national dynamic optimization models representing the energy producing and consuming sectors in each region. They optimize the development of these sectors under given fuel import prices and useful energy demand over a predefined time horizon. The development of national energy systems can be subject to energy and environment constraints such as availability of fuel, penetration rates of certain technologies, emission standards, and emission ceilings. The model databases contain a wide range of conversion and end-use technologies such as conventional, renewable energy, efficient fossil fuel burning, combined heat and power, and energy conservation technologies in the demand sectors [4].

LEAP is a scenario-based energy-environment modeling tool. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price and so on. LEAP has been used to develop local, national and regional energy strategies, conduct GHG mitigation assessments, and train professionals in sustainable energy analysis [5].

MARKAL is a family of bottom-up energy system models that depicts both supply and demand. MARKAL provides policy

Table 4. **Existing energy planning models and their grouping by the analytical approach and methodology**

	Models	Bottom-up	Hybrid	Optimization	Simulation	Toolbox
1	EFOM (Energy Flow Optimization Model)	X		X		
2	LEAP (Long-range Energy Alternatives Planning)	X			X	
3	MARKAL (MARKet ALlocation)	X		X		
4	MESAP (Modular Energy System Analysis and Planning software)		X	X		
5	MESSAGE (Model for Energy Supply Systems Analysis and General Environment)	X		X		
6	MIDAS (Multinational Integrated Demand and Supply)		X		X	
7	PowerPlan (Interactive simulation model)	X			X	
8	RETScreen (Renewable Energy Technology Screening)	X				X
9	EnergyPlan		X		X	

Table 5. **Energy planning models and the main characteristics**

Models	Developer	Home page	Geographic applicability	Data requirements	Default data included	Time horizon	Reference materials	Language
EFOM	European Union	–	Local, national, regional, global	Medium–high	Detailed description of energy supply and end-uses technologies	Medium to long-term	Description in some literature	English
LEAP	Stockholm Environment Institute	www.energycommunity.org	Local, national, regional	Low–medium	Database with costs, performance and emission factors	Long-term	Manual and training materials free on web site	English, French, Spanish, Portuguese, Chinese
MARKAL	IEA/ETSAP (Energy Technology System Analysis Project)	www.etsap.org	Local, national, regional, global	Medium–high	Detailed description of end-uses and (renewable) energy technologies possible	Long-term	Manual available to registered users	English
MESAP	IER, Stuttgart University, Germany	–	Local, national, regional, global	Low–medium	Database with fuel costs and emission factors	Long-term	Description in some literature	English
MESSAGE	IIASA (International Institute for Applied Systems Analysis) Austria	http://www.iiasa.ac.at	Local, national, regional, global	Medium–high	Database with fuel costs and emission factors	Medium to long-term	Description free on web site	English
MIDAS	European Union	–	Local, national, regional, global	Low–medium	Database with fuel costs and emission factors	Long-term	Description in some literature	English
PowerPlan	Center for Energy and Environmental Studies University of Groningen	http://www.fwn.rug.nl/ivem/soft.htm	Local, national, regional	Low–medium	Database with fuel costs and emission factors	Medium to long-term	Manual and demo version free on web site	English, Dutch
RETScreen	Natural Resources Canada	www.retscreen.net	Local	Technology specific	Extensive defaults: weather data, products, costs, etc.	One year in steps of one hour	Manual and training materials free on web site	Multiple
EnergyPlan	Sustainable Energy Planning Research Group at Aalborg University	http://energy.plan.aau.dk/	Local, national, regional	Low–medium	Database with costs, distribution and emission factors	Primarily static analysis	Manual and training materials free on web site	English

makers and planners in the public and private sector with extensive details on energy producing and consuming technologies, and it can provide an understanding of the interplay between the macroeconomy and energy use. As a result, this modeling framework has helped national and local energy planning and the development of carbon mitigation strategies [6].

MESAP is a modular energy planning package developed with the specific needs of developing countries in mind. It is designed as a flexible planning package providing energy analysts and planners with tools to perform complex energy analysis. It consists of basic techniques for energy planning, a set of tested energy modules, and data management and processing software. At the heart of MESAP is a network-oriented database. Its objective is to assist in energy and environmental policy analysis and planning [4].

MESSAGE is generally used for the optimization of energy supply systems. However, other systems supplying specified demands of goods, which have to be processed before delivery to the final consumer, could be optimized. The objectives include resource extraction analysis, estimation of the import / export of energy, energy conversion analysis, energy transport and distribution analysis, analysis of final energy utilization by consumer, recommendations for environmental protection and investment policies, and analysis of opportunity costs [7].

MIDAS is a large-scale energy system planning and forecasting model. It performs dynamic simulation of the energy system, which is represented by combining engineering process analysis and econometric formulations. The model is used for scenario analysis and forecast. MIDAS covers the whole energy system and ensures, on an annual basis, a consistent and simultaneous projection of energy demand, supply, pricing and costing so that the system is in both quantity- and price-dependent balance. The model output is a time-series of detailed EUROSTAT energy balance sheets, lists of costs and prices by sector and fuel, and a set of capacity expansion plans including emission data [8].

PowerPlan is an interactive simulation model with which the future for the electricity supply system can be planned. PowerPlan is a so-called forecasting model: given an existing power system and year, an electricity supply system future will be simulated. It is thus not an optimization model, but a model from which the consequences of decisions can be evaluated (a "What-If" model) [9].

The RETScreen International Clean Energy Project Analysis Software is the leading tool specifically aimed at facilitating the pre-feasibility and feasibility analysis of energy technologies. The core of the tool is the standardized and integrated project analysis software which can be used worldwide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of proposed energy-efficient and renewable energy technologies [10].

The EnergyPlan model is a computer model for Energy Systems Analysis. The main purpose of the model is to assist in designing national energy planning strategies on the basis of technical and economic analyses of the consequences of different national energy systems and investments. The model can be used for different kinds of energy system analyses: technical analysis, market exchange analysis and feasibility studies [11].

We could test three of the selected models (LEAP, RETScreen and EnergyPlan) because of their free availability and distribution in personal and academic projects. The MESSAGE model is available for users with additional request of entering data, and it was not considered in this paper. The PowerPlan model has the only freely available demo version.

The RETScreen and the EnergyPlan models are more useful for single new energy capacity planning. Also, the RETScreen model has the possibility of detailed technical equipment selection and the financial indicator calculation. The EnergyPlan model is more useful for the whole energy sector balance planning of the country, but as compared with the LEAP model have no possibilities to input the external assumption information and data of sectors such as industry, mining, etc. Both models (RETScreen and EnergyPlan) could be used in the pre-feasibility study of the new capacity planning projects. The results of the models give a marginal difference; the models are indicated for scenarios development and could be useful for comparing the fundamental technological processes [12].

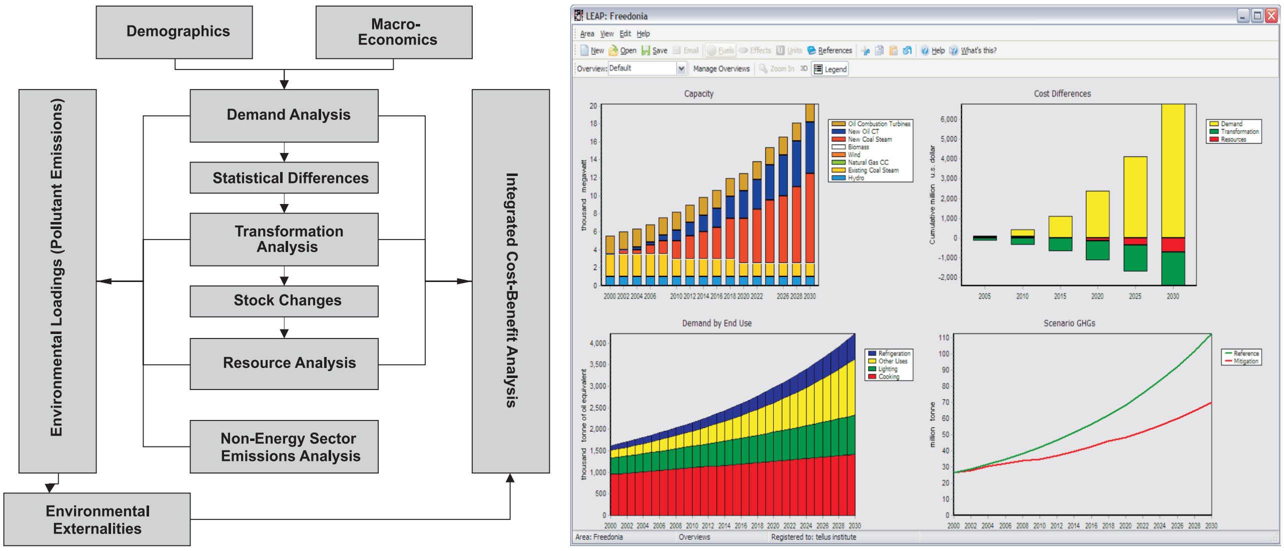

Fig. 2. LEAP calculation flows and the result reporting

For elaborating scenarios of the development of the Estonian energy system in the conditions mentioned above, the LEAP model was selected as the preferred framework in which the most essential reasons for selecting were a free use of the model and training materials, public technical support and discussion, user-friendly interface. It allows for a transparent arrangement of the data, various possible scenarios and can be developed energy system configurations. The main benefit of LEAP is that it is a tool that helps the user to combine and assess data in a consistent framework. This makes it easier to organize the data in an intuitive and accessible manner, and to get a grasp on the information. LEAP calculation flows and the result reporting are presented in Fig. 2 [3].

5. RESULTS

We evaluated different types of energy planning models according to the main characteristics and found suitable ones for the Estonian energy sector. The main characteristics of energy modeling approaches are summarized in Table 2. A wide range of models were reviewed (Table 3), and we selected nine models that have the bottom-up or hybrid approach, linear programming and by the methodology are simulation, optimization and toolbox models. In Table 4, they are grouped by the analytical approach and methodology. The main characteristics of the selected models are presented in Table 5.

Comparing the freely available energy planning models, the LEAP model was selected as the preferred framework for elaborating the scenarios of the Estonian energy system development. The RETScreen and the EnergyPlan energy models are more useful for single new energy capacity planning. The EnergyPlan model is also used for the whole energy sector balance planning of a country, but has low input data for calculation in different sectors of the country, such as industry, mining, etc. compared with the LEAP model.

6. CONCLUSIONS

The paper presents an analysis of energy planning models and the results of investigating the adaptability of energy planning models for the Estonian energy system in the conditions of oil-shale-based electricity supply shortage, taking into account the main engagements and figures of the electricity sector by year 2015.

The description of the main characteristic of the models and their comparison are presented. The different types of existing energy planning models are reviewed, and nine models were selected for a more detailed analysis.

Analysis of the adaptability the freely available models is given, and the Long-range Energy Alternatives Planning (LEAP) as the preferred model selected to elaborate the scenarios of developing the Estonian energy system and mitigating the environmental impacts of electricity production by using new, less environment-damaging technologies are presented.

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ENERGETIKOS MODELIŲ CHARAKTERISTIKŲ ANALIZĖ IR JŲ TAIKYMAS ESTIJOS ENERGETIKOS RINKAI

Santrauka

Pastaraisiais metais sukurta daug modelių, skirtų energetinės sistemos analizei, įskaitant poreikių prognozes, tiekimo prognozes ir politikos kaitos poveikius energetinei sistemai. Šie modeliai pagrįsti skirtingomis fundamentaliomis teorijomis, koncepcijomis, apima daug matematinių algoritmų ir yra labai skirtingi. Kyla klausimas, kurį iš modelių tinkamiausia taikyti.

Estija yra vienintelė Europoje šalis, turinti svarbią skalūnų pramonę. Estijoje 95 % elektros energijos yra pagaminama skalūnų elektrinėse. Dėl griežtų aplinkosaugos reikalavimų iškyla grėsmė ateities elektros tiekimui iš skalūnų elektros jėgainių.

Pateikiamas vykdomas mokslinis projektas, kurio tikslas – analizuoti energijos planavimo modelius, skirtus Estijos energetinės sistemos plėtros scenarijams detalizuoti esant skalūnų elektrinių tiekiamos elektros trūkumui, atsižvelgiant į pagrindinius energetikos sektoriaus duomenis iki 2015 metų.

Raktažodžiai: energetikos planavimas, modeliavimas, vartojimas, paklausa, prognozės, optimizavimas, ekonominė pusiausvyra

Надежда Дементьева, Андрес Сиирде

АНАЛИЗ ЭНЕРГЕТИЧЕСКИХ МОДЕЛЕЙ И ИХ ПРИМЕНЕНИЕ ДЛЯ ЭСТОНСКОГО ЭНЕРГЕТИЧЕСКОГО РЫНКА

Резюме

В последние годы разработано большое количество моделей для анализа энергетических систем, включая прогнозы потребления и снабжения, а также влияния политических изменений на общую энергетическую систему. Энергетические модели основаны на разных фундаментальных подходах и концепциях, в них используется целый ряд математических алгоритмов. Поэтому эти модели значительно различаются, и возникает вопрос, какая модель наиболее пригодна для определенной цели или ситуации.

Эстония является единственной страной в Европе, которая имеет сланцедобывающую промышленность. Здесь 95 % электроэнергии производится на электростанциях, работающих на сланце. Страны Балтии переживают сложную ситуацию разрушения монополии и создания свободного рынка электроэнергии в соответствии с договоренностями с Европейским Союзом. Кроме того, Эстония находится в переходном периоде развития сланцевого энергетического сектора. Тенденции либерализации и изменения в эстонском энергетическом рынке, связанные с жесткими технологическими и экологическими требованиями Европейского Союза, приводят к возникновению необходимости разработки новых сценариев развития энергетического сектора Эстонии с уменьшением воздействия на окружающую среду производства электроэнергии и использованием новых, менее вредных, технологий. Эта статья представляет текущий научно-исследовательский проект, цель которого – анализ моделей энергетического планирования для разработки сценариев развития эстонской энергетической системы в условиях дефицита электроэнергии, основанной на сланце, с учетом основных обязательств и целей электроэнергетического сектора к 2015 году.

Ключевые слова: энергетическое планирование, моделирование, энергетическая модель, потребление, спрос, прогноз, оптимизация, экономическое равновесие, симуляция

PAPER II

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OPTIMIZATION OF NARVA DISTRICT HEATING NETWORK AND ANALYSIS OF COMPETITIVENESS OF OIL SHALE CHP BUILDING IN NARVA

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AS Narva Elektrijaamad owns two the world's largest oil shale-fired power plants – Balti Elektrijaam (Balti Power Plant) and Eesti Elektrijaam (Eesti Power Plant). The new fluidized-bed energy block No. 11 of Balti Power Plant is operated in cogeneration mode to provide the district-heating system of Narva. The energy market prices of heat for all consumer groups have increased significantly. High heat losses and poor technical condition of the old district-heating networks decrease the future of centralized heating, and consumers make choice in favor of local heating. High heat losses of Narva district heating are caused by poor thermal insulation and over-dimensioning of pipes. Objective estimation of actual conditions of district-heating networks and technical-economical argumentation for renovation and expansion of networks should be carried out to increase the share of heat production based on CHP and to decrease fuel consumption. For minimization of heat distribution expenses DH network should be optimized. The opportunities of building heat supply alternatives in Narva are also investigated. Four scenarios of heat supply alternatives were analyzed using energy planning models.

Introduction

At building, capacity of combined heat and power plants (CHP) follows basically from thermal loading. The new fluidized-bed energy block No. 11 of Balti Power Plant is operated in cogeneration mode to provide the district-heating system of Narva.

Poor condition of district-heating (DH) networks and unreliable heat supply can decrease the future of district heating, and consumers have to make choice for different heat supply alternative. Often the decentralized heating is no effective solution for regional heat supply strategy decreasing

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the potential of combined heat and power production. Objective estimation of actual conditions in DH networks and technical-economical argumentation for their renovation and expansion should be carried out to increase the share of heat production based on CHP and decrease fuel consumption. For decreasing the heat distribution cost, DH networks should be optimized.

Main characteristic parameters of the DH network of Narva city and their difference from the optimal values are estimated and compared with the typical Swedish networks [1]. The current comparison gives an example for economic optimization of Narva old unoptimized district-heating network. The purpose of optimization is to get minimal costs of heat distribution. The potential for increasing the efficiency of Narva DH network was established.

For analysis of competitiveness of oil shale CHP the opportunities of building heat supply alternatives in Narva also are investigated. Four scenarios of heat supply alternatives were analyzed using two energy-planning models. The economical reasonability of building new units near Narva city is given.

Methodology

Method of estimation of DH networks

The major characteristic parameter for estimating the efficiency of the DH networks is heat loss factor q_{hlf}. The heat loss factor is a ratio of the heat loss to the quantity of heat supplied to the DH network. The heat loss factor does not depend only on the efficiency of pipe insulation. It depends on the following parameters:

- The overall heat transfer coefficient K_o, in $W/(m^2 \cdot K)$, which characterizes the efficiency of pipe insulation;
- The specific surface area of the distribution pipes A/L, in m^2/m, which characterizes the average size of the district heating pipes;
- The degree-hour number $\int \Theta d\tau$, in °C·h, which indicates the level of water distribution temperature relative to the annual average of the outdoor temperature;
- The specific heat supply Q/L, in MWh/m, which characterizes the concentration of the district heating demand.

Where

A – surface area of the distribution pipes, m^2;

L – pipes' length, m;

Θ – difference between water average temperature and outdoor temperature, °C;

τ – duration of difference between average and outdoor temperatures of water, h;

Q – annual quantity of the heat supplied to the district-heating network, MWh.

The overall heat transfer coefficient can be calculated on the basis of design data of the district networks or estimated from the heat loss measurements. In the present work the overall heat transfer coefficient is calculated on the basis of the annual heat losses. The annual heat losses are calculated as the difference between the heat supplied to the DH network and the heat measured at the consumers.

The heat loss factor is given by

$$q_{hlf}=\frac{Q_{hlf}}{Q}=\frac{K_o\cdot A\cdot\int\Theta d\tau}{Q}=K_o\cdot\frac{(A/L)\cdot\int\Theta d\tau}{(Q/L)}, \tag{1}$$

where Q_{hlf} – the annual distribution heat loss, MWh.

The overall heat transfer coefficient K_o is given by

$$K_o=\frac{q_{hlf}}{\left[\dfrac{(A/L)\cdot\int\Theta\, d\tau}{(Q/L)}\right]}, \text{ W/(m}^2\cdot\text{K)}. \tag{2}$$

The average diameter of the district heating pipes d_a is given by:

$$d_a=\frac{A/L}{2\cdot\pi}, \text{ m.} \tag{3}$$

For analyzing the efficiency of the DH network, heat loss factor can be divided into two parts: the overall heat transfer coefficient and the distribution parameter. The distribution parameter is given by

$$q_{dp}=\frac{q_{hlf}}{K_o}=\frac{(A/L)\cdot\int\theta d\tau}{(Q/L)}, \text{ (m}^2\cdot\text{K)/W.} \tag{4}$$

The question how to select the optimal diameter of pipes in which a fluid is transported represents a classical optimization problem [2-4]. Figure 1 shows qualitatively how an economic optimum can be found for the diameter of the district-heating pipe. Total cost is the sum of costs for pipeline installation, for heat losses, and for pumping power. Of these three cost elements, the costs of pipeline installation and heat losses increase strongly with diameter, while the pumping power drops rapidly ($K_{pumping}$ ~D_s^5) with diameter increasing.

Optimization of this kind usually assumes that the flow rate is constant when the diameter is varied. This method was developed to be as simple as possible yet complete and accurate enough for design calculations.

Dynamic simulation models of DH networks today are also very popular. One type of the mathematical model involves a full physical modeling of the network [6] and in the other type of model DH network is replaced by a simplified one [7].

Water velocities and friction losses in pipes of Estonian old DH networks, as a rule, are much lower than their optimum values. This situation

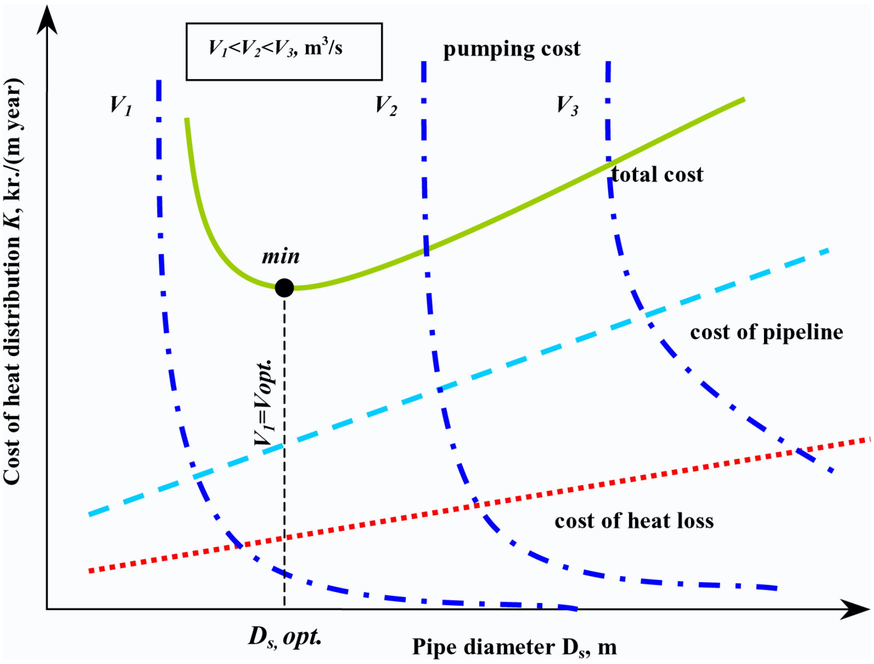

Fig. 1. Economic optimization of pipe diameter.

exists because old networks were designed for a much bigger load taking into account growing potential. In the present time the heat load of consumers is 15–30% less than designed (in some cases up to 2 times less).

Pumping costs in old networks with overdimensioned pipes are much less than in new optimized networks. At the same time heat losses in old networks with overdimensioned and badly insulated pipes are many times higher. The saving in heat losses gives a great increase in the total DH distribution cost.

As a rule of thumb, many DH networks in Denmark and in other European countries have been designed by applying a friction loss of 100 Pa/m [2, 4]. Estonian old networks are designed also by applying similar friction loss of about ~80 Pa/m [8], but real friction losses are much less. This situation exists because old networks were designed for a much bigger load taking into account growing potential.

Analysis of heat energy supply alternatives

Heat energy supply alternatives in Narva city were modelled to investigate the feasibility and economical reasonability of the use of oil shale condensing extraction turbine block comparing with the other alternatives, such as biomass CHP, natural gas CHP and boilerhouse. The CHP usage could increase the share of heat produced by CHP and decrease fuel consumption.

Modeling is one of complicated forecasting methods. Mathematical modeling means the description of economical vision by using mathematical formulas, equations and inequalities. Models become often useful when analyzing complex systems with large amount of data. The most popular tool for new capacity planning is energy planning models, where using comparatively low input data could get reliable results.

Models are built for various purposes and consequently have different characteristics and applications. The energy models could be classified as follows: by purposes of energy models (general and specific), the model structure (internal and external assumptions) and the analytical approach (top-down, bottom-up, hybrid), by the methodology, the mathematical approach (linear, mixed-integer and dynamic), geographical coverage, sectoral coverage, the time horizon and data requirements [9].

In recent years, the total number of available energy models has grown extremely because of the expanding computer possibilities. The main modeling problem has been the lack of baseline data or inexact input data, and the model's results are used in the case of reliable and accurate baseline data. For investigation of the opportunities of new heat energy supply alternatives in Narva two energy planning models, EnergyPlan and RETScreen® International models, were reviewed. These models were analysed and the scenarios were calculated for comparing the difference between the results of two chosen models and finding out whether the results are reliable.

The EnergyPlan model is a computer model for energy system analysis. The main purpose of the model is to assist the design of national energy planning strategies on the basis of technical and economic analyses of the consequences of different national energy systems and investments. The model can be used for different kinds of energy system analyses: technical analysis, market exchange analysis and feasibility studies. The EnergyPlan model consists of the following overall structure components: Front page, Input, Cost, Regulation, Output and Settings. Inputs defined by the user are presented in three sections: Input, Cost, and Regulation [10].

RETScreen® International is a clean energy awareness, decision-support and capacity building tool. The core of the tool consists of a standardized and integrated clean energy project analysis software that can be used worldwide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of energy efficient and renewable energy technologies. Five steps of the standard project analysis of RETScreen flow charts are Energy Model, Cost Analysis, Greenhouse Gas Analysis, Financial Summary and Sensitivity & Risk Analysis.

High-quality but low-cost pre-feasibility and feasibility studies are critical to helping the project proponent “screen out” projects that do not make financial sense, as well as to helping focus development and engineering efforts prior to construction. Each step of this process could represent an increase of one order in expenditures and a halving of the uncertainty in the project cost-estimate. This is illustrated in Fig. 2, where the level of un-

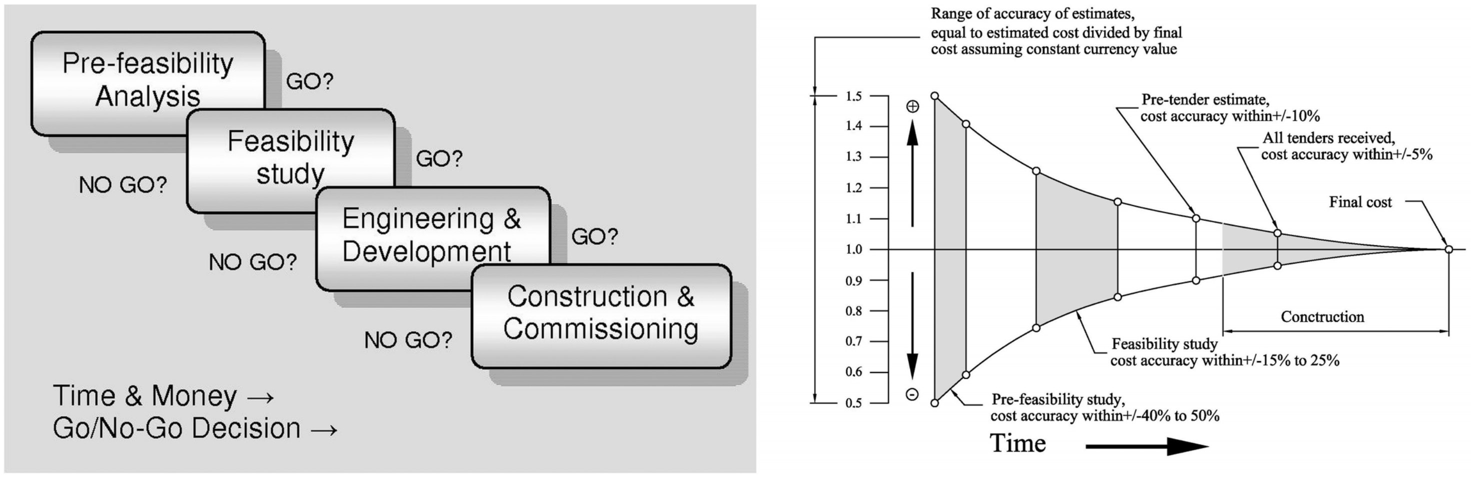

Fig. 2. The usual several steps of the project and accuracy of project cost estimate.

certainty in estimates decreases from ±50% to 0%, while the energy project implementation process is progressing from the pre-feasibility to the commissioning stages [11].

Using these two models four scenarios (pre-feasibility studies) of building new capacity in Narva were generated and analyzed:

- Scenario 1: Oil shale CHP unit at Balti PP.
- Scenario 2: CHP unit, where the main fuel is natural gas.
- Scenario 3: Boilerhouse, where the main fuel is natural gas.
- Scenario 4: Biomass/Peat CHP unit.

First, the selection of scenarios was based on local oil shale availability from this region where oil shale-based Narva Power Plant works, and second on the possibility to compare cogeneration technology and boilerhouse economy.

The annual heat energy demand in Narva is about 475 GWh. Expected thermal capacity of units is about 170–175 MW and electrical capacity about 60–65 MW. The annual electricity production at units in the case of Scenarios 1, 2 and 3 would be approximately 160 GWh. The main input data for these analyses are the production of electricity and heat, fuel types, fuel costs, efficiency of processes and the investments of projects according to the available data. The investment and other costs are informative and needed further research for more accurate analysis. Also the existing library of distribution data of Nord Pool electricity prices in 2006 in the EnergyPlan model was used. For all four scenarios the primary energy consumption, CO_2 emissions and production price were calculated and compared.

Using RETScreen Software in the Financial Summary worksheet it is possible to calculate several financial feasibility indicators such as internal rate of return IRR, the net present value (NPV) and simple payback of the projects.

The internal rate of return IRR is the discount rate that causes the NPV of the project to be zero. It is calculated by solving the following formula for IRR:

$$0 = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n}, \tag{5}$$

where N is the project life in years and C_n – the cash flow for the year n.

The net present value NPV of a project is the value of all future cash flows, discounted at the discount rate, in today's currency. It is calculated by discounting all cash flows as given in the following formula:

$$NPV = \sum_{n=0}^{N} \frac{\tilde{C}_n}{(1+r)^n}, \tag{6}$$

where $\tilde{C}_n$ is the after-tax cash flow, r – the discount rate.

The simple payback SP is the number of years it takes for the cash flow (excluding debt payments) to equal the total investment, which is equal to the sum of the debt and equity:

$$SP = \frac{C - IG}{(C_{ener} + C_{capa} + C_{RE} + C_{GHC}) - (C_{O\alpha M} + C_{fuel})}, \qquad (7)$$

where C is the total initial cost of the project, IG – the incentives and grants, C_{ener} – the annual energy savings or income, C_{capa} – the annual capacity savings or income, C_{RE} – the annual renewable energy production credit income, C_{GHC} – the GHG reduction income, $C_{O\alpha M}$ – the yearly operation and maintenance costs incurred by the clean energy project, C_{fuel} – the annual cost of fuel or electricity [11].

Results

- The relative heat losses in the Narva old network are about 18–19%. In Swedish typical networks relative heat losses are 7–9%, and there is the similar heat demand concentration than in Narva: 5–7 MWh/m, but much better heat insulation of pipes: overall heat transfer coefficient is 0.9–1.1 W/(m^{2}K) (in Narva 1.8–2.0 W/(m^{2}K)), more than two times less than in Narva network. Efficiency of heat insulation for Narva network, which is estimated by the overall heat transfer coefficient, is about three times less than the same value for the ordinary Swedish networks. Total overall heat transfer coefficients before and after prospective optimization for Narva DH network are presented in Fig. 3.

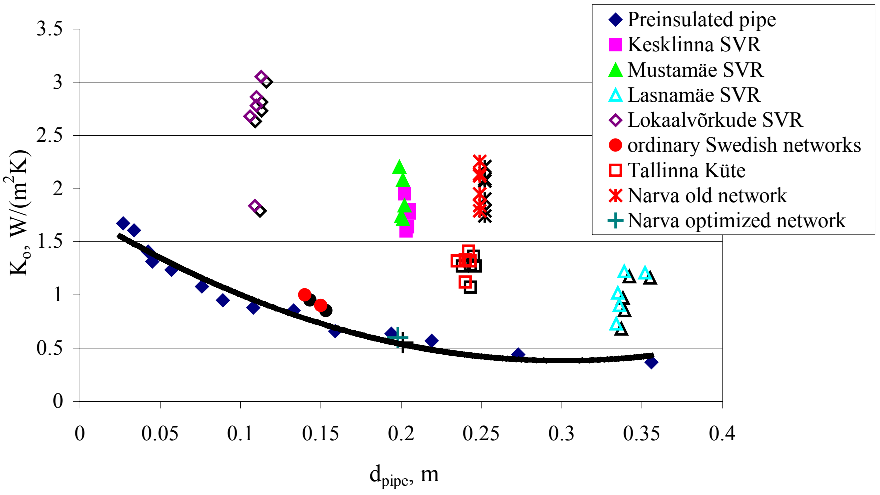

Fig. 3. Total overall heat transfer coefficient before and after prospective optimization for Tallinn and Narva district heating networks.

- After optimal selection of network pipes' diameters (new optimal average diameter will be 0.198 m), according to consumers real heat demand and total renovation of pipes (replacing by the preinsulated pipes), relative heat losses drastically decrease. Relative heat losses, for example in Narva network decrease from 17–18% to 7–8%. As we can see, decreasing potential of heat losses is very big. After optimization and total renovation of old networks, heat losses can decrease up to three times. Recently, a considerable tendency for reduction of the overall heat transfer coefficient in the DH networks in Narva was observed (from 2.3 W/(m^{2}K) to 1.8–2.0 W/(m^{2}K)). This reduction is caused by replacement of old thermal insulation of DH network sections with new one (main pipelines TM1 and TM2 in 2003–2005). Several "wet" sections of the network can significantly increase the value of the heat transfer coefficient. Replacement of these sections will significantly decrease the overall heat transfer coefficient. Table 1 presents the major characteristic parameters found for Narva old unoptimized DH network. For the observed network also optimization calculations were done, and it was determined, how much these values would improve.
- The calculations made in the EnergyPlan and RETScreen model and their results are presented in simplified tables (Tables 2, 3), and comparison of the results of two energy planning models is presented in Table 4. The simplified tables use the relative information about fuel, investments, primary energy and production prices considering that in the case of changes in fuel and investment costs the price relations will be same. The production prices include the electricity and heat energy production prices and could be put together because of the same combined power plant total output. Generally, the RETScreen model uses a hybrid method for calculation the heat and electrical energy price, where variable costs are shared: fuel, electricity and environmental charges in accordance with the physical method as well as fixed costs in accordance with heat and electricity production. The electricity price could be the input parameter as well. The Energy Plan model uses the existing library of electricity and heat prices. In this case the existing library of distribution data of Nord Pool electricity prices in 2006 was used.
- The difference between the results of EnergyPlan and RETScreen models for production price is approximately 5% in Scenarios 1, 2 and 4, primary energy consumption per production for all scenarios is about 4%, and for CO_2 emissions in Scenarios 1, 2 and 3 is 4.3% (see Table 4). The higher production price in Table 3 compared with the results of Table 2 at the same investment and with better use of primary energy is explained by more accuracy and the difference in the characteristics of the equipment of the second model (RETScreen). In this analysis the investment and other costs are informative and need further research for a more accurate analysis.

Table 1. **The major characteristic parameters for Narva district heating network before and after prospective optimization and comparison with ordinary Swedish networks**

Average year	Supplied heat, MWh	Used heat, MWh	Network heat losses, MWh	Network heat losses, %	Degree-hours 10^5, °C h	q_{hlf}	L, m	d_a, m	A/L, m^2/m	V/L, m^3/m	Q_{suppl}/L, MWh/m	Q_{used}/L, MWh/m	Q_{suppl}/V, MWh/m^3	$Q_{heat\ loss}/L$, MWh/m	K_o, $W/(m^2K)$	q_{it}, $(m^2K)/W$
Narva old network	577 402	474 400	103 002	17.8	4.9	0.178	68 569	0.249	1.56	0.15	8.4	6.9	57.5	1.5	2.0	0.091
Narva new optimized network	510 453	474 400	36053	7.1	4.9	0.071	68 569	0.198	1.24	0.06	7.4	6.9	120.9	0.5	0.7	0.082
Ordinary Swedish networks					5.6	0.07–0.085			0.88–0.942	0.031–0.035	5–6		162–170	0.35–0.43	0.9–1.1	

Table 2. **Results of applying EnergyPlan model**

EnergyPlan	Fuel, kr/MWh	Investments, mln.kr/MW	Production price, kr/MWh	Primary energy consumption per production, GWh/GWh	CO_2 emission, Mt
1. Scenario (Oil shale unit at Balti PP)	54	1.3	1 080	1.42	0.33
2. Scenario (CHP – main fuel is nat. gas)	305	1.0	1 165	1.19	0.15
3. Scenario (Boilerhouse – main fuel is nat. gas)	305	0.5	665	0.85	0.11
4. Scenario (Biomass/Peat CHP)	62	1.0	861	1.23	0.00

Table 3. **Results of applying RETScreen model**

RETScreen	Fuel, kr/MWh	Investments, mln.kr/MW	Production price, kr/MWh	Primary energy consumption per production, GWh/GWh	CO_2 emission, Mt
1. Scenario (Oil shale unit at Balti PP)	54	1.3	1 255	1.39	0.32
2. Scenario (CHP – main fuel is nat. gas)	305	1.0	1 177	1.15	0.15
3. Scenario (Boilerhouse – main fuel is nat. gas)	305	0.5	665	0.81	0.10
4. Scenario (Biomass/Peat CHP)	62	1.0	870	1.18	0.00

Table 4. **Results of comparing EnergyPlan and RETScreen models**

EnergyPlan vs. RETScreen	Production price, kr/MWh		Primary energy consumption per production, GWh/GWh		CO_2 emission, Mt	
1. Scenario (Oil shale unit at Balti PP)	–175	–14.0%	0.03	2.0%	0.01	3.7%
2. Scenario (CHP – main fuel is nat.gas)	–12	–1.1%	0.04	3.3%	0.01	3.5%
3. Scenario (Boilerhouse – main fuel is nat.gas)	0	–	0.04	4.4%	0.01	5.6%
4. Scenario (Biomass/Peat CHP)	–9	–1.1%	0.05	4.2%	0.00	–

- The RETScreen energy model has more detailed input requirements for new energy capacity planning and therefore it could be more useful for such kind of analyses. Also the RETScreen model has the possibility of detailed selection of technical equipment and calculation of financial indicators. The EnergyPlan model is more useful for planning the energy balance for the whole country and for the new capacities while it does not enable to calculate the financial feasibility indicators and payback of the project. However, both of the models could be equally used for the pre-feasibility study of new capacity planning projects. The differences in the results of reviewed models are marginal, the models are indicative of scenarios' development and could be useful for comparing the fundamental technological processes. One of the advantages of using these models is that they allow to get reliable results using comparatively low input data.
- According to the pre-feasibility study, using given input data all of scenarios have positive NPV, IRR and could be applicable for a more detail analysis. For further analysis the additional research of input data is needed. The most attractive scenario is Scenario 4 with building biomass/peat CHP; simple payback is about 7 years. The building of CHP or boilerhouse (Scenario 2, 3) using natural gas could be under consideration, because of the high cost of fuel, despite of less initial investment costs of the project in Scenario 3 the payback is 11 years. The payback of Scenario 2 is 13 years. The usage of oil shale as the main fuel of unit in Scenario 1, where payback period is 9 years, could be competitive and has obvious advantages: availability of the local fuel and stable supply, the possibility to generate electricity additionally, the location of new unit in the existing power plant. The results of the financial feasibility indicators are presented in Fig. 4.

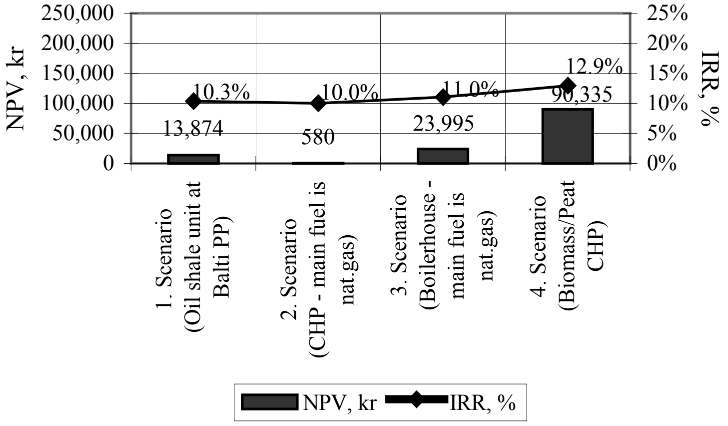

Fig. 4. Financial indicators.

Conclusions

This paper presents the estimation of actual conditions of Narva district heating networks, technical-economical argumentation for renovation of district-heating networks and the results of four scenarios modeling heat supply alternatives in Narva using energy-planning models.

After optimization and total renovation of old networks, heat losses can decrease up to three times. The major characteristic parameters for Narva district-heating network before and after prospective optimization are presented, and comparison with ordinary Swedish networks is given.

Modeling of heat energy supply alternatives in Narva is analyzed to compare the economy of oil shale condensing extraction turbine block usage with biomass CHP, natural gas CHP and boilerhouse. The results of reviewed models differ marginally depending on the difference in the characteristics of the equipment of the models. The models are indicative for scenarios' development and could be useful for comparing the fundamental technological processes. The advantage of using these models is that they allow to get reliable results using comparatively low input data. The financial analysis shows the competitiveness and the advantages of using the oil shale CHP.

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PAPER III

Dementjeva N., Siirde A. Analysis of the current Estonian energy situation and adaptability of LEAP model for Estonian energy sector. Accepted for publication in Power Engineering.

ANALYSIS OF THE CURRENT ESTONIAN ENERGY SITUATION AND ADAPTABILITY OF LEAP MODEL FOR ESTONIAN ENERGY SECTOR

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Abstract

The trend of liberalization and changes in the Estonian energy market, related to the European Union's strict technological and environmental requirements, give rise to the need to develop the modeling of new scenarios for the energy sector in Estonia by mitigating the environmental impacts of electricity production and using new, less environment-damaging technology. The easiest way to develop scenarios is to use energy planning modeling.

Modeling is one of the complicated forecasting methods. In recent years, a large number of energy planning models have been developed. They vary considerably and the question arises which model is the most suited for a certain purpose or situation.

The current paper presents the one part of carried out study under the PhD thesis done at Tallinn Technical University in the Department of Thermal Engineering. The objectives of the study were analysis and evaluation of the existing energy models in the world; development of the selection criteria and selection of the several energy models for the analysis of the energy market in Estonia; practical testing of the applicability of the selected models to Estonia.

The first part of this paper gives an overview of the current energy supply in Estonia and future changes of the Estonian energy production system related to the restrictions in technology and environment. The second one presents the result of testing of LEAP model that was using for the elaboration the scenarios of the Estonian energy system's development.

Keywords

Keywords: energy planning model, electricity market, LEAP, reference energy system, liberalization, energy demand, electricity production.

Резюме

Тенденция либерализации и изменения в эстонском энергетическом рынке, связанные с жесткими технологическими и экологическими требованиями Европейского Союза, приводят к возникновению необходимости разработки новых сценариев развития энергетического сектора Эстонии с уменьшением воздействия на окружающую среду производства электроэнергии и использование новых, менее вредных технологий. Самый простой способ для разработки сценариев является использование моделирования энергетического планирования.

Моделирование является одним из сложных методов прогнозирования. В последние годы большое количество моделей энергетического планирования были разработаны. Модели энергетическое планирования значительно отличаются и встает вопрос о выборе модели для определенной цели или ситуации.

Текущая статья представляет собой одну часть проведенных исследований в рамках диссертации, подготовленной в Таллиннском Техническом Университете на факультете теплоэнергетики. Задачи диссертации являются анализ и оценка существующих моделей энергетики в мире, разработка критериев отбора и выбор несколько моделей энергетики для анализа энергетического рынка в Эстонии; практическая проверка применимости выбранных моделей для Эстонии.

Первая часть статьи дает обзор современного энергоснабжения в Эстонии и будущих изменений в Эстонской энергосистеме, связанные с ограничениями в области технологий и окружающей среды Вторая часть представляет собой результат тестирования LEAP модели, которая использовалась для разработки сценариев развития Эстонской энергосистемы.

Ключевые слова

Модель энергетического планирования, рынок электроэнергии, LEAP, энергосистема, либерализация, потребление энергии, производство электроэнергии.

1. INTRODUCTION

Energy is an essential part of the social and economic development of any country and nation. Due to increasing awareness of the environmental impact of energy production, the goal of national energy policies is not only to guarantee a secure and cost-effective energy supply, but also to minimize the harmful side effects and, eventually, develop a sustainable energy system.

The trend of liberalization and changes in the Estonian energy market, related to the European Union's strict technological and environmental requirements, give rise to the need to develop the modeling of new scenarios for the energy sector in Estonia by mitigating the environmental impacts of electricity production and using new, less environment-damaging technology. The easiest way to develop scenarios is to use energy planning modeling. Instead of developing a new model, the existing ones can be used, but the key question is to decide which model should be used. Energy models are based on different fundamental approaches and concepts, and employ a range of mathematical algorithms.

In order to decide which model is better to use, it was explained the model characteristics, structures, data and modelling methods in the previous paper [1].

As a part of the work, there were presented the different scenarios of Estonian energy system development in the conditions of oil shale-based electricity supply shortage, taking into account the main engagements and figures of electricity sector by year 2020. The aim of this paper is to a simplified model of Estonian energy system with a transparent structure. The purpose of the model is to demonstrate the usage of the model's features in connection with the Estonian electricity system.

2. CURRENT ENERGY SUPPLY IN ESTONIA

Today more than 90% of Estonian electricity demand is covered by local oil shale power plants. The most significant of them are the Eesti Power Plant with installed electrical capacity 1 615 MW and thermal capacity 84 MW and the Balti Power Plant with installed electrical capacity 765 MW and thermal capacity 400 MW. The main achievement of late years is introduction of a new technology of oil shale combustion in the circulating fluidized bed at Unit 8 of the Eesti Power Plant and Unit 11 of the Balti Power Plant. Application of the new technology has enabled improvement of the operational efficiency as well as considerably decreased the amount of hazardous emissions.

Iru Power Plant, the biggest producer of thermal power and the third biggest producer of electrical power in Estonia with electrical capacity 190 MW and heat capacity is 648 MW (398 MW in co-generation mode). The main fuel of Iru Power Plant is natural gas. AS Kohtla-Järve Soojus (Kohtla-Järve District Heating Network) uses also oil shale and its electrical capacity 30 MW and thermal capacity is 138 MW. Power plants using renewable energy, such as Virtsu wind turbine, Linnamäe and Keila-Joa hydroelectric plants, produced 1.2% of the annual electrical energy production in 2007 [2].

The total electricity and heat production in Estonia by energy sources in 2008 are presented in Figure 1 and 2 [3].

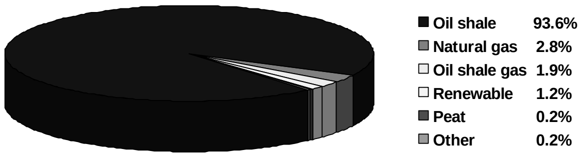

Figure 1. Total electricity generation by energy sources in 2008.

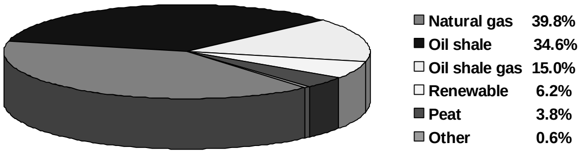

Figure 2. Total heat generation by energy sources in 2008.

2.1 Estonian electricity market

The market structure has similarities to Scandinavian model with the System responsibility given to the transmission system operator.

The Estonian electricity market has a monopolistic market where one energy enterprise (Eesti Energia AS) dominates. Its prices are under state regulation, but it is dictating conditions and connection fees to small producers for access to its network. The Estonian domestic market is divided into three categories, sales to the open market, sales to the closed market and external sales to network operators.

In 2008 the total net generation from all power plants in Estonia was 9 498 GWh, a decrease of 1 456 GWh over the year or 13 % compared to the year 2007 [3]. The total electricity consumption in Estonia was 7 836 GWh, a decrease of 97 GWh over the year or 1 % compared to the year 2007. The Estonian electricity net generation and consumption by months in 2008 is presented in Figure 3 [4].

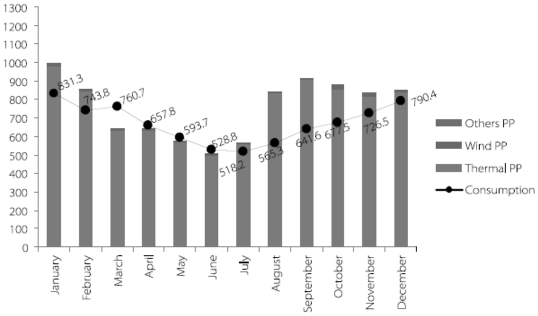

Figure 3. Estonian electricity net generation and consumption by months in 2008.

According to the European Union requirements the Estonian electricity market must be opened on 35% by the end of 2009 and fully opened by the year 2013. Today Estonian electricity market has been open for eligible customers whose annual consumption exceeds 40 GWh since 1999. These consumers have a right to purchase electricity from any producer or seller in the market and an obligation to pay for network services. At present there are 13 eligible costumers in the system, they consume about 16 % of energy in Estonia. Non-eligible customers can purchase their electricity from the grid company they are physically connected to or from the seller named by that grid company. Grid companies and sellers selling energy to non-eligible customers can purchase that energy from power plants using oil-shale mines in Estonia as the primary energy source or from small producers with capacities less than 10 MW.

Liberalization of electricity market or opening of electricity production and sales for competition will raise system's efficiency and quality of services in Estonia, but considering the small size of Estonian electricity market, the complication of power system control, shortage of generation capacity, costs of operating the market, volatile prices and possible lowering of supply security and reliability due to insufficient investments in the whole region can easily surpass the expected positive effect of liberalization [5].

The strategic objective of Estonian electricity sector development plan until 2018 is to assure the optimal functioning and development of Estonian power system in the market economy conditions and to assure in the long-term outlook the proper supply of electricity to the consumers at lowest price possible, at the same time implementing all reliability and environmental conditions.

Since March 2009 Eesti Energia's electricity weighted average price limit is 32.5 €/MWh. In addition to domestic electricity sales Eesti Energia exports electricity via Nordic energy exchange Nord Pool to Finland. Electricity export price is determined by Nord Pool Finland regional price level. Additionally the Eesti Energia Group exports electricity to the other Baltic States [6].

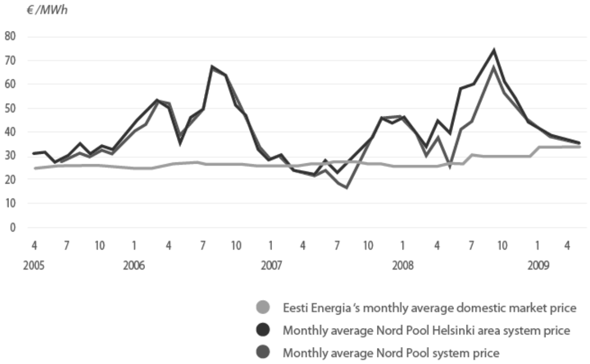

Figure 4. Eesti Energia's average domestic market price by months 2005-2009

The main engagements and figures concerning to energy sector development by year 2020 is followed [7]:

- diversification of energy sources used in the generation sector, including construction of the Estonian nuclear power plant by 2020 and decreasing the dependency on oil-shale generation;
- by 2010, renewable electricity will form 5.1 % of gross consumption;
- by 2020, electricity produced in combined heat and power production stations will account for 20 % of gross consumption;
- to open Estonian electricity market for 35 % in 2009 and for all consumers in 2013;
- the limitation of energy consumption;
- preconditions will be established for connecting with the energy systems of the Nordic and Central European countries, including the new interconnection Estlink 2 between Estonia and Finland.

After year 2015 about 70 % of available installed net generation capacity of existing oil shale based units will be shut down. In operation will be two new fluidized bed boilers in the Narva Power plants, the second generation unit in Iru Power plant and small power plants. The Estlink cable between Finland and Estonia, commissioned right at the end of 2006, increased the opportunities for power imports and export from and to Estonia.

The major investments in electricity production will be:

- Peat and biomass CHP-s with gross capacity of 100 MW in 2010 2015
- Wind turbines with gross capacity of 618 MW by the year 2015
- 1st oil shale CFBC unit with gross capacity of 270 MW in 2015
- 2nd oil shale CFBC unit with gross capacity of 270 MW in 2016
- Natural gas combined cycle plant with gross capacity of 100 MW in 2012
- Nuclear plant with gross capacity of 600 MW in 2020.

The electricity supply and demand forecast in Estonia are presented in Figure 5 [8].

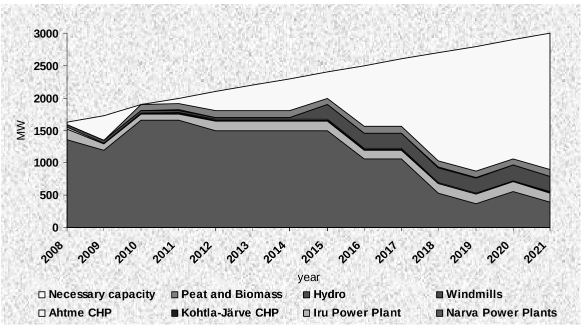

Figure 5. Electricity supply and demand forecast

The countries with liberalized markets need new methods for energy planning, because the uncertainty is increasing and the problems become larger. Also there are more transactions to process, more data and information to manage and planning processes and more attention needs to be paid on how to formulate and implement the models efficiently. In practice, it is not feasible to develop own models for energy planning exercises by energy planners and researchers, more effective to use existing models, but the key question is to decide which model should be used.

3. ENERGY SYSTEM MODELS CLASSIFICATION AND BASIC STRUCTURE

Models are built for various purposes and consequently have different characteristics and applications.

The nine ways of classification are presented:

1. Purposes of energy models:
   - General: forecasting, exploring, backcasting.
   - Specific: energy demand, energy supply, impacts, appraisal, integrated approach, modular build-up.
2. The model structure: internal assumptions and external assumptions
3. The analytical approach: top-down, bottom-up and hybrid.
4. The underlying methodology: econometric, macro-economic, economic equilibrium, optimization, simulation, spreadsheet/toolbox and backcasting.
5. The mathematical approach: linear programming, mixed-integer programming, dynamic programming.
6. Geographical coverage: global, regional, national, local, or project.
7. Sectoral coverage: single-sectoral models and multi-sectoral models.
8. The time horizon.
9. Data requirements.

Such classification of energy models is helpful for understanding their need, their roles and their specificity in relation to the studies under consideration [9].

The structure of a model is often illustrated with a reference energy system (RES), which is a network depicting flows of commodities through various processes. This network includes all energy carriers involved with primary supplies (e.g., mining, petroleum extraction, etc.), conversion and processing (e.g., power plants, refineries, etc.), and end-use demand for energy services (e.g., boilers, automobiles, etc.). The building blocks depicted in Figure 6 represent the simplified Reference Energy System (RES) [10].

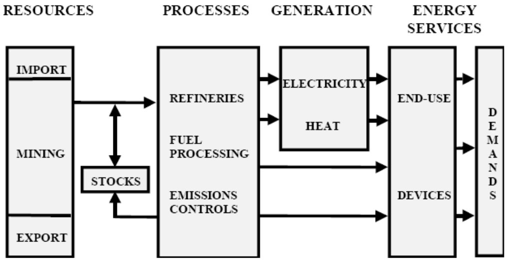

Figure 6. Reference Energy System (RES)

According to the model's main characteristics it was suggested the selection criteria of the energy planning models from the point of view of the Estonian energy sector in [1]. It was also selected the several existing energy models for the analysis of the energy market in Estonia: EFOM, TIMES, LEAP, MARKAL, MESAP, MESSAGE, MIDAS, PowerPlan, RETScreen and EnergyPlan. The application of these models is given in the next Chapter.

3.1 Application of existing models

The selected energy planning models have been used and applied to various practical cases. This Chapter presents the overview of applications of selected models.

The effects on the entire energy system by a reduction in the amount of imported energy are studied by applying the EFOM model to the energy situation in Denmark [11] and for investigation of emission control strategies for Turkey [12].

TIMES model is usually applied to the analysis of the entire energy sector, but may also be applied to study in detail single sectors (the electricity and district heat sector). Using the TIMES framework there were developed several works for different countries: an energy system model for the Southern African Development Community region [13], the Nordic Electricity Production System [14], estimation of CO2 marginal abatement costs for Portugal [15], and several works of optimisation the electricity, heat and natural gas markets of the 25 trading regions in [16], [17].

Hundreds of government agencies, academic organizations, utilities and consulting companies worldwide use LEAP for a variety of tasks including, energy forecasting, greenhouse mitigation analysis, integrated resource planning, production of electricity and heat energy sectors and energy scenario studies. Numerous countries have used LEAP to prepare greenhouse gas mitigation assessments as part of their initial national communications to the United Nations Framework Convention on Climate Change. The Department of Energy of the Government of the Philippines represents National Energy Plan [18] and scenarios for five cities in South Africa have been modelled using LEAP [19]. LEAP model was used in comparison of scenarios of oil shale long term trends in the report of Estonian Electricity Sector Development Plan until 2018 [7].

MARKAL is a well-known model in Estonia for modelling entire energy sector. The analysis has been carried out using the Estonian MARKAL model [20], [21]. Recently were defended two doctoral theses in Tallinn University of Technology based on MARKAL calculations [22], [23].

An industrial module was developed to form part of the applicable energy system analysis tools, namely a Reference Energy Model for PlaNet (PlaNet: Planning Network) under the MESAP (Modular Energy System Analysis and Planning Environment) for Slovenia [24] and for neighbouring Latvia [25].

MESSAGE was used in [26] for the entire energy supply system in countries of the Baltic States.

MIDAS covers the whole energy system, including energy demand by sector and fuel, power generation, oil refineries, natural gas, solid fuel production, imports and energy market prices. The results of MIDAS application in France and EU are given in [27], [28].

PowerPlan model is simulating a countries' power sector and its emissions. The study based on scenarios developed in PowerPlan was carried out in China's power sector [29].

RETScreen model includes the whole energy sector and the list of applications of RETScreen model is given in [30]. Numerous examples for implementing commercially viable energy efficient and renewable energy technologies around the world such as Wind Farm in Ireland, Solarwall on High School in Northern Canada, Photovoltaic Water Pumping System in Africa, Solar Water Heating at Vancouver International Airport and many others. It was made the investigation of future project of waste incineration plant building at Iru Power Plant in Estonia.

In 2005-2007, the EnergyPlan model was used in the EU-funded project DESIRE (Dissemination Strategy on Electricity Balancing for Large Scale Integration of Renewable Energy). In six regions in Denmark, Germany, the UK, Poland, Spain and Estonia, models of the electricity supply were made and the magnitude of CHP regulation systems was evaluated against other relevant measures including the expansion of interconnectors [31].

4. THE RESULTS OF ADAPTABILITY OF LEAP MODEL

4.1 Energy power system development scenarios

According to selection criteria done for current study, the LEAP model was selected as the preferred framework for elaborating the scenarios of development of the Estonian energy system, where the most essential reasons of selecting were free using of model and training materials, public technical support and discussion, user friendly interface; it allows for transparent arrangement of the data, various possible scenarios and can be developed energy system configurations.

The whole study presents the adaptability of freely available models for users: RETScreen, EnergyPlan and LEAP. The more detailed result of application RETScreen, EnergyPlan models is given in the calculations of the heat energy supply alternatives modelling in Narva city [32]. This Chapter includes only the results of testing of LEAP model.

The significant part of the study is devoted to input data collection for LEAP model, and could not be reflected in the full extent in this paper. Using the input data, taking mainly from the Statistics of Estonia [3], Eesti Pank's forecasts [33], energy savings in Eesti Energia AS webpage [6] and the training exercises of LEAP [34], it was made the database of Estonia key assumptions in LEAP model.

Using Estonia LEAP model were elaborated eight alternative scenarios for Estonian electricity production system during the period 2009 - 2035 in the conditions mentioned in Chapter 2:

1. Reference scenario (REF)

The Reference Scenario represents a today's situation of Estonia's energy sector. This scenario is characterized that the CFBC oil shale units will be renovated and the production of electricity is dominated by oil shale. The penetration of various renewable energy technologies such as wind and biomass power generation is considered as per the existing situation today. In the REF, the -12.3 % GDP growth rate in the year 2009 and the forecasts are according to Eesti Pank's revised forecast of the first quarter [33].

2. Low-growth scenario (LG)

This scenario assumes a low GDP growth rate of -15.3 % in the year 2009 relative to the -12.3 % GDP growth rate assumed in the REF scenario in the same year and the forecasts are according to Eesti Pank's revised forecast of the first quarter [33]. All other assumptions and other parameters are similar to the REF scenario.

3. High-growth scenario (HG)

This scenario assumes a high GDP growth rate of -8.4 % from year 2009 relative to the GDP growth rate of -12.3 % assumed in the REF scenario in the same year and the forecasts are according to Eesti Bank's revised forecast of the first quarter [33]. This scenario shows an optimistic view of the Estonian economy. All other assumptions and other parameters are similar to the REF scenario.

4. Nuclear capacity scenario (NUC)

In this study, nuclear-energy-based power generation has been included as per Eesti Energia plans. The installed capacity of nuclear power plants is 600 MW in year 2020. The nuclear energy-based power generation capacity is expected to be in the amount of 5000 GWh per year from the nuclear power plan starting. Additional information about nuclear power plant scenarios is given in [22].

5. Renewable energy scenario (REN)

In this scenario, high penetration of renewable energy is considered. Amount of potential places are identified for wind-based power plants in the country such as offshore wind farms in Estonian waters and wind farm on the closed ash field at AS Narva Elektrijaamad. The availability capacity of wind power plants is assumed to increase till 618 MW by the year 2012 as compared to the existing 117 MW in 2009.

6. Hybrid scenario (HYB)

This scenario is a combination of the REF, REN, and NUC scenarios. It describes the energy forecast of the Estonian economy by incorporating the entire range of renovation and development of oil shale technologies, penetration of nuclear energy - based power generation technologies, the renewable energy sources and the starting up of new gas turbine with capacity of 100 MW after year 2012. The GDP growth rate is as in REF scenario.

7. Low-growth-hybrid scenario (LHYB)

This scenario combines a low GDP growth rate like in LG scenario and the HYB scenario with energy technologies development.

8. High-growth-hybrid scenario (HHYB)

This scenario combines a high GDP growth rate like in HG scenario coupled with high nuclear capacity and penetration of renewable energy as in HYB scenario. This scenario is representative of the most optimistic scenario in terms of both economic growth and technological achievements.

4.2 LEAP model results across various scenarios

A comparative analysis of the key results across all the scenarios is presented in this Chapter.

Figure 7 presents the sectoral energy demand across various scenarios that include commercial, transport, industrial and residential sector. The requirements shown under the demand category shows only the primary energy required to meet domestic demands. In the REF, REN, NUC and HYB scenario, the total energy demand increases annually 1.43 % during the period 2009 2035, taking into account the economic growth projections of country in the these scenarios. However, it increases annually by 0.7 % and 1.6 % in the LG and HG scenarios, respectively. It has been observed also that in the LHYB and HHYB scenario, the total sectoral energy demand increases the same as LG and HG scenarios.

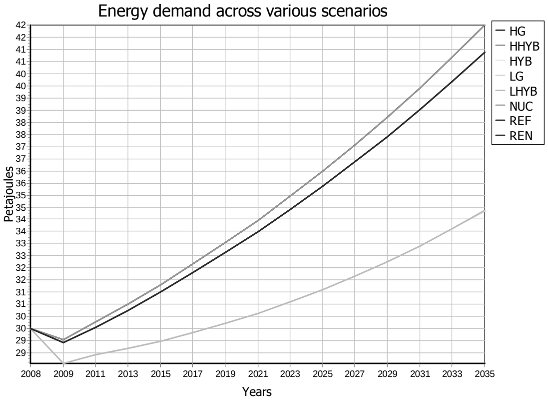

Figure 7. Energy demand across various scenarios

Figure 8 shows primary energy consumption across various scenarios, where the primary energy requirements under the resources category account for converted energy system requirements.

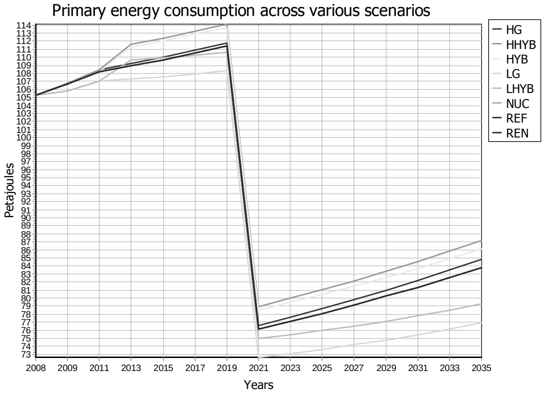

Figure 8. Primary energy consumption across various scenarios

In the REF, REN, NUC scenarios the primary energy consumption decreases annually 0.76 % during the period 2009-2035, taking into account the shortage of electricity production of country after year 2020 in the REF. It decreases annually by 1.0 % in the LG and 0.72 % in HG scenarios. It also decreases annually by 0.67 % in HYB scenario, 0.92 % in the LHYB and 0.64 % in HHYB scenario. The sharp drop of primary energy consumption after year 2020 is caused by the reduction in consumption of oil shale by almost 50 % of total amount. This reduction in consumption of oil shale is attributed to the oil shale old units closing after year 2020. Estonia has applied for a transition period for solving oil shale-based energy sector development and reducing the hazard emissions.

Figure 9 presents a comparison of electricity generation across various scenarios. In the REF, LG and HG scenario, the total electricity generation decreases from 9 TWh in 2008 to 5.5 TWh in 2035, the shortage of electricity generation will be 3.6 TWh in 2035. The oil-shale-based generation decreases from 8.7 TWh in 2008 in the REF scenario to 4.5 TWh in the 2035. Gas-based generation has the same level as in base year, because no new power plants will be built in this scenario. The growth of biomass and wind power generation is 0.36 TWh and 0.3 TWh respectively. In HYB, HHYB and LHYB scenarios, the total power generation increases from 9 TWh in 2008 to 12.7 TWh in 2035. The oil-shale, gas, biomass and wind-based energy production are the same as in the REF scenario. However, there exists variation in the technology deployment for power generation across these scenarios: it is added new nuclear and gas power generation that replaces oil-shale-based generation. In the NUC scenario, the total power generation increases by 1.4 TWh in 2035 and in the REN scenarios, the shortage of electricity generation will be 2.2 TWh in 2035.

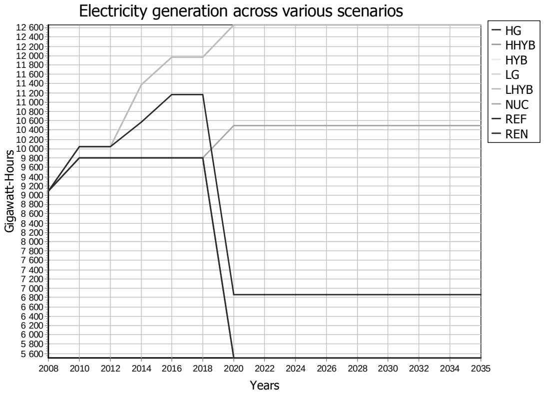

Figure 9. Electricity generation across various scenarios

For simplifying it was shown the trends of CO_2 emissions in the REF and HYB scenarios over the modelling time frame in Figure 10. The REN, NUC, LG and HG scenarios have the same trend as in REF scenario. The HHYB, LHYB scenarios have the same total emissions of carbon dioxide as in HYB scenarios. As it shown in REF and HYB scenarios the total emissions decrease sharply after year 2020 due to shut down the old units at Narva Power Plant and reduction of oil- shale-based electricity production. The HYB scenario has the advantage of new nuclear plant that does not have CO_2 emissions, however in the REF scenario about half of the electricity needed to import after the year 2020. The trends of amount of carbon dioxide emissions are similar to energy generation trends. The trends of energy generation in REF scenario are different from HYB scenario by new natural gas power plant with additional electrical capacity 100 MW.

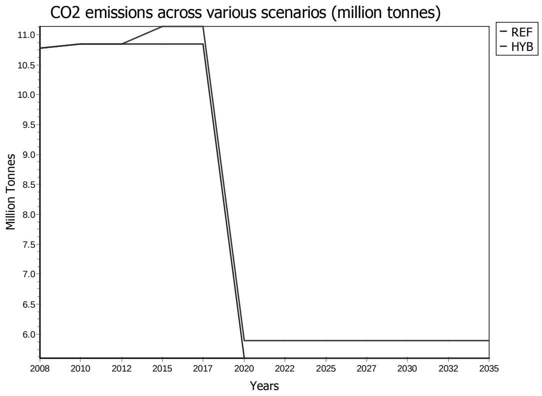

Figure 10. CO2 emissions in million tones

5. CONCLUSIONS

This paper presents the result of testing of LEAP model that was using for the elaboration the scenarios of the Estonian energy system's development. An overview of the current energy supply in Estonia and future changes of the Estonian energy production system related to the restrictions in technology and environment was given. The major investments in Estonian electricity production system were defined.

The application of the selected existing energy models across several countries was provided. According to the situation in Estonian energy market described in Chapter 2 it was elaborated eight alternative scenarios for Estonian electricity production system during the period 2009 – 2035. A comparative analysis of the key results across all the scenarios was presented in Chapter 4.2.

The LEAP model, a user-friendly and freely available tool, demonstrated the usage of the model’s features in connection with the Estonian electricity system and it could be suitable for elaborating the scenarios for the whole energy sector and for electricity and heat single sectors, including external assumptions. Using the provided database of Estonia key assumptions in LEAP model, the model may serve as a basis for a more accurate model of Estonia and for further research.

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PAPER IV

Dementjeva N., Siirde A. Analysis of the current Estonian energy situation and its modelling for developing future forecasts using energy planning models. 6th International Symposium „Topical Problems in the Field of Electrical and Power Engineering“. Doctoral School of Energy and Geotechnology. Kuressaare, Estonia, January 12-17, 2009, pp. 77-80.

6th International Symposium
„Topical Problems in the Field of Electrical and Power Engineering“
Kuressaare, Estonia, January 12-17, 2009

Analysis of the current Estonian energy situation and its modelling for developing future forecasts using energy planning models

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Abstract

Estonia is a small country where electricity production, mining and processing of oil shale is a regional economic complex with their difficulties. Estonia is facing a complex situation in breaking up the monopoly and developing a free electricity market. Estonia has applied for a transition period for solving oil shale-based energy sector development and opening of electricity market issues in the European Union accession negotiation. These changes give rise to new planning challenges and necessity to review the different types of energy planning models for modelling energy sector.

Modelling is one of complicated forecasting methods. In recent years a large number of energy planning models have been developed. Energy planning models become often useful when analyzing complex systems have a lot of data; they help to understand relationships between different parameters and work out scenarios of development in any country. Afterwards, the model may serve as a basis for more accurate model of the country.

This paper presents an ongoing research project where the objective is to analyze energy planning models to elaborate the scenarios of development of Estonian energy sector. This paper gives an overview of the current energy supply in Estonia, future changes of Estonian energy production system related to the restrictions in technology and environment. The energy system models classification and their basic structure are provided and future framework is given.

Keywords

Energy planning, modelling, energy model, supply, demand, forecast

Introduction

Energy is a vital input for social and economic development of any nation. Due to increasing agricultural, industrial activities and standard of living in any country, the total energy consumption and the use of fossil fuels are also increasing. The combustion of fossil fuels causes the hazardous emissions that are the main reason of global warming. The main goal of energy policies of every country is not only to guarantee a secure and cost-effective energy supply, but also to minimize the harmful effects and develop a sustainable energy system. The trend of liberalization and changes in Estonian energy market related to European Union technological and environmental requirements, gives rise to new planning challenges and necessity to review the different types of models such as energy planning models, supply–demand models, forecasting models, emission reduction models, optimization models to work out different ways of energy development of energy sector. The review paper on energy modelling will help the energy planners, researchers and policy makers widely. In practice, it is not feasible to develop own models for energy planning exercises by energy planners and researchers, more effective to use existing models, but the key question is to decide which model should be used.

1. Current energy supply in Estonia

Today 90% of Estonian electricity demand is covered by local oil shale power plants. The most significant of them are the Eesti Power Plant with installed electrical capacity 1 615 MW and thermal capacity 84 MW and the Balti Power Plant with installed electrical capacity 765 MW and thermal capacity 400 MW. The main achievement of late years is introduction of a new technology of oil shale combustion in the circulating fluidized bed at Unit 8 of the Eesti Power Plant and Unit 11 of the Balti Power Plant. Application of the new technology has enabled improvement of the operational efficiency as well as considerably decreased the amount of hazardous emissions.

Iru Power Plant, the biggest producer of thermal power and the third biggest producer of electrical power in Estonia with electrical capacity 190 MW and heat capacity is 648 MW (398 MW in co-generation mode). The main fuel of Iru Power Plant is natural gas. AS Kohtla-Järve Soojus (Kohtla-Järve District Heating Network) uses also oil shale and its electrical capacity 30 MW and thermal capacity is 138 MW. Power plants using renewable energy, such as Virtsu wind turbine, Linnamäe and Keila-Joa hydroelectric plants, produced 1.2% of the annual electrical energy production in 2007 [1].

The total electricity and heat production in Estonia by energy sources in 2007 are presented in Figure 1 and 2 [3].

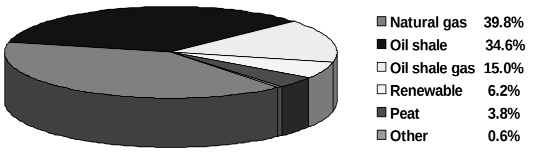

Figure 1. Total electricity generation by energy sources in 2007.

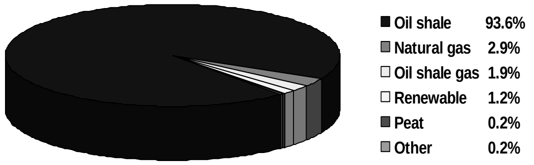

Figure 2. Total heat generation by energy sources in 2007.

1.1 Estonian electricity market

The Estonian electricity market has a monopolistic market where one energy enterprise (Eesti Energia AS) dominates. Its prices are under state regulation, but it is dictating conditions and connection fees to small producers for access to its network. The Estonian domestic market is divided into three categories, sales to the open market, sales to the closed market and external sales to network operators.

In 2007 the total net generation from all power plants in Estonia was 10518 GWh, an increase of 2411 GWh over the year or 23% compared to the year 2006. The Estonian electricity net generation and consumption by months in 2007 is presented in Figure 3 [2].

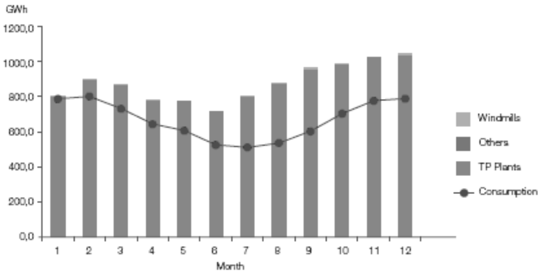

Figure 3. Estonian electricity net generation and consumption by months in 2007

The total sales of electrical energy to customers in the open market were 1646 GWh, to customers in the closed market 4,267 GWh and to network operators 607 GWh. The sales of electrical energy in the open market increased by 1102 GWh (67%), in the closed market by 748 GWh (18%), and to network operators by 185 GWh (30%) over the previous year. The sales to corporate customers increased by 697 GWh or 24% and to residential customers by 346 GWh or 31%. In 2007 the total sales in the domestic market came to 7,012 GWh, an increase of 444 GWh over the year or 6% compared to the year 2006 [3].

According to the European Union requirements the Estonian electricity market must be opened on 35% by the end of 2008 and fully opened by the year 2013. Today Estonian electricity market has been open for eligible customers whose annual consumption exceeds 40 GWh since 1999. These consumers have a right to purchase electricity from any producer or seller in the market and an obligation to pay for network services. At present there are 13 eligible costumers in the system, they consume about 16 % of energy in Estonia. Non-eligible customers can purchase their electricity from the grid company they are physically connected to or from the seller named by that grid company. Grid companies and sellers selling energy to non-eligible customers can purchase that energy from power plants using oil-shale mines in Estonia as the primary energy source or from small producers with capacities less than 10 MW.

Liberalization of electricity market or opening of electricity production and sales for competition will raise system’s efficiency and quality of services in Estonia, but considering the small size of Estonian electricity market, the complication of power system control, shortage of generation capacity, costs of operating the market, volatile prices and possible lowering of supply security and reliability due to insufficient investments in the whole region can easily surpass the expected positive effect of liberalization [4].

The strategic objective of Estonian electricity sector development plan until 2015 is to assure the optimal functioning and development of Estonian power system in the market economy conditions and to assure in the long-term outlook the proper supply of electricity to the consumers at lowest price possible, at the same time implementing all reliability and environmental conditions. The main engagements and figures of electricity sector by year 2015 are followed:

- To achieve percentage of electricity production from renewable energy resources 5,1 % of gross consumption in 2010
- To achieve percentage of electricity production from electricity and heat co-generation 20 % of gross consumption in 2020
- To open Estonian electricity market for 35 % in 2009 and for all consumers in 2013

The major investments in electricity production will be:

- Peat and biomass CHP-s with gross capacity of 100 MW in 2010-2015
- Wind turbines with gross capacity of 200 MW by the year 2015.
- 1st oil shale CFBC unit with gross capacity of 270 MW in 2015
- 2nd oil shale CFBC unit with gross capacity of 270 MW in 2016 [5].

The electricity supply and demand forecast in Estonia are presented in Figure 4 [6].

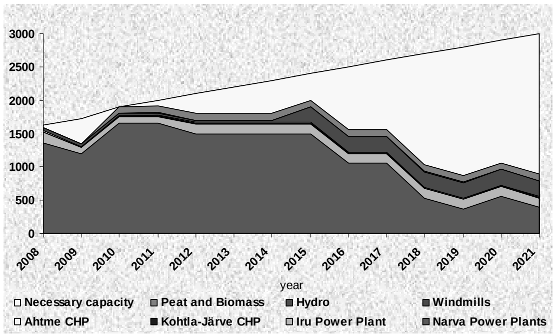

Figure 4. Electricity supply and demand forecast

The countries with liberalized markets need new methods for energy planning, because the uncertainty is increasing and the problems become larger. Also there are more transactions to process, more data and information to manage and planning processes and more attention needs to be paid on how to formulate and implement the models efficiently. In practice, it is not feasible to develop own models for energy planning exercises by energy planners and researchers, more effective to use existing models, but the key question is to decide which model should be used.

2. Energy system models classification and basic structure

In recent years, the total number of available energy models has grown extremely because of the expanding computer possibilities. As a consequence, these models vary considerably and the question arises which model is most suited for a certain purpose or situation. In energy system planning, various and often contradictory goals, such as minimizing costs and greenhouse gas emissions while assuring the reliability of energy supply, are present.

The nine ways of classification are presented:

1. Purposes of Energy Models:
   - General: forecasting, exploring, backcasting
   - Specific: energy demand, energy supply, impacts, appraisal, integrated approach, modular build-up
2. The Model Structure: Internal Assumptions and External Assumptions:
   - Internal Assumptions: degree of endogenization, description of non-energy sectors, description end-uses, and description supply technologies.
   - External Assumptions: population growth, economic growth, energy demand, energy supply, price and income elasticities of energy demand, existing tax system and tax recycling.
3. The Analytical Approach: Top-Down or Bottom-Up
4. The Underlying Methodology: Econometric, Macro-Economic, Economic Equilibrium, Optimization, Simulation, Spreadsheet/Toolbox, Backcasting, and Multi-Criteria.
5. The Mathematical Approach: linear programming, mixed-integer programming, dynamic programming.
6. Geographical Coverage: Global, Regional, National, Local, or Project.
7. Sectoral Coverage: single-sectoral models and multi-sectoral models.
8. The Time Horizon: Short, Medium, Long Term
9. Data Requirements: qualitative, quantitative, monetary, aggregated, disaggregated.

Such classification of energy models is helpful for understanding their need, their roles and their specificity in relation to the studies under consideration [7].

The structure of a model is often illustrated with a reference energy system (RES), which is a network depicting flows of commodities through various processes. This network includes all energy carriers involved with primary supplies (e.g., mining, petroleum extraction, etc.), conversion and processing (e.g., power plants, refineries, etc.), and end-use demand for energy services (e.g., boilers, automobiles, residential space conditioning, etc.). The demand for energy services may be disaggregated by sector (i.e., residential, manufacturing, transportation, and commercial) and by specific functions within a sector (e.g., residential air conditioning, heating, lighting, hot water, etc.). The building blocks depicted in Figure 5 represent the simplified Reference Energy System (RES) [8].

There are many existing energy models that are using widely over the word. The most popular of them are MARKAL, EFOM, MESSAGE, TIMES, ENPEP, LEAP, ENERGY2020, MICROMELODIE, RETscreen.

Existing models for local energy planning frequently use forecasting methods (econometrics) for projecting future energy demand and the bottom-up approach rather than a top-down approach to allow for a detailed, disaggregated analysis. The bottom-up approach is also necessary to enable a detailed description of the different supply technologies (conventional as well as renewable).

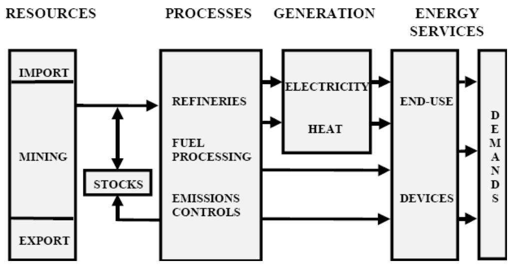

Figure 5. Reference Energy System (RES)

Concerning the mathematical approach, linear programming has a clear advantage in that it allows for simple programming and can easily be understood by planners because no special expertise is needed. In this case the problem can be solved in a straightforward way by using standard algorithms.

Linear optimization is aimed to find the optimal value of a linear function of a certain number of variables usually labelled $x_1, x_2 \ldots x_n$. An optimization problem in an n-dimensional variable $x = (x_1, \ldots x_n)^T$ can be generally written as:

$$\min[z = z(x_1, \ldots x_n)] \quad (1)$$

subject to

$$f_i(x) \geq b_i \,, \qquad i = 1, \ldots, m$$

$$u_j \geq x_j \geq l_j \qquad j = 1, \ldots, n$$

z is called the objective function. In the case of energy system *z* might be total costs, emissions of a specific substance or the amount of employment created by the system, for example, or a combination of them,

u_j, l_j, f_i and b_i are used to set constraints that define the space of allowed or feasible solutions.

These constraints may include restricted availability of resources or maximum allowable emission levels. If both *z* and *f* are linear in *x,* i.e.

$$z = cx = \sum_{j=1}^{n} c_j x_j \quad (2)$$

$$f = Ax \Leftrightarrow \forall i : f_i = \sum_{j=1}^{n} a_{ij} x_j \quad (3)$$

where *A* is the constraint matrix and all l_j are non-negative $l \geq 0$ [9].

So the set of models for local energy planning should consist of a modular package of models with exploring purposes and should at least include models for energy demand, energy supply, impacts and an appraisal.

3 Conclusions and future work

Due to the changing mentioned above in Estonian economy, energy market, and environmental requirements, the main goals of the work are to investigate the energy-planning models, to simplify the model of Estonian energy system with a transparent structure. The purpose of chosen model is to demonstrate the usage and adaptability of the energy model in connection with the Estonian energy system and work out some scenarios of the Estonian energy sector development by mitigating the environmental impacts of electricity production and using new, less environment-damaging technologies. Afterwards, the model may serve as a basis for more accurate model of Estonia.

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Appendix B
CURRICULUM VITAE

Appendix B

CURRICULUM VITAE

First name	Nadežda
Last name	Dementjeva
Date and place of birth	27.01.1978, Estonia
Citizenship	Estonian
Family status	Unmarried
Contact	Sinimäe 11-33, 13816 Tallinn, Estonia; Telephone: +372 53967467; E-mail: nadezda.dementjeva@energia.ee
Organization	Eesti Energia AS Iru Elektrijaam, Peterburi tee 105, 74114 Maardu, Estonia
Current position	Chief Specialist

Education

Educational institution	Year of graduation	Education
Tallinn University of Technology	2005	Master degree
Tallinn University of Technology	2001	Bachelor degree
Jõhvi Vene Gümnaasium	1996	Secondary Education

Professional Employment

Period	Organisation	Position
2005-present	Eesti Energia AS Iru Elektrijaam, Operation and Analysis department	Chief specialist
2004-2005	OÜ Iru Elektrijaam, Operation and Analysis department	Engineer
2002-2004	Eesti Energia AS Iru Elektrijaam, Technical department	Analyst

Language skills

Language	Level
English	Average
Estonian	Average
Russian	Mother tongue

Training courses

Period	Organisation
November 08-March 09	Weekend University, Module 2,3,5; Eesti Energia AS
October 2005-April 2007	English and Estonian language courses, Generum OÜ
November 2006	Seminar „Metrology changes. Implementing of Measuring Instruments Directive 2004/22/EC, AS Metrosert
December 2005	Professional course of spreadsheet calculation, BCS Koolitus
December 2005	Seminar „Current challenges of metrology, AS Metrosert
October 2005	Project Management, Audentes Ariko

Research Interest

Investigations of the energy planning modeling and models, energy power system development and forecast modeling.

Appendix B

ELULOOKIRJELDUS

Eesnimi	Nadežda
Perekonnanimi	Dementjeva
Sünniaeg ja -koht	27.01.1978, Eesti
Kodakondsus	Eesti
Perekonnaseis	Vallaline
Kontaktandmed	Sinimäe 11-33, 13816 Tallinn, Estonia; Telephone: +372 53967467; E-mail: nadezda.dementjeva@energia.ee
Töökoht	Eesti Energia AS Iru Elektrijaam, Peterburi tee 105, 74114 Maardu, Estonia
Ametikoht	Peaspetsialist

Hariduskäik

Õppeasutus	Lõpetamise aeg	Haridus
Tallinna Tehnikaülikool	2005	Tehnikateaduste magister
Tallinna Tehnikaülikool	2001	Tehnikateaduste bakalaureus
Jõhvi Vene Gümnaasium	1996	keskharidus

Teenistuskäik

Töötamise aeg	Organisatsiooni nimetus	Ametikoht
2005-käesoleva ajani	Eesti Energia AS Iru Elektrijaam, Režiimi-ja analüüsi teenistus	Peaspetsialist
2004-2005	OÜ Iru Elektrijaam, Režiimi ja analüüsi teenistus	Arvestus ja režiimiinsener
2002-2004	Eesti Energia AS Iru Elektrijaam, Tehnikaosakond	Käiduanalüütik

Keelteoskus

Keel	Tase
Inglise	Kesktase
Eesti	Kesktase
Vene	Emakeel

Täiendusõpe

Õppimise aeg	Organisatsiooni nimetus
November 08-Märts 09	Nädalalõpu ülikool 2, 3, 5. moodul Eesti Energia AS
Oktoober 2005-Aprill 2007	Inglise- ja eestikeele kursused, Generum OÜ
November 2006	Seminar “Mõõteseaduse muudatused. Mõõtevahendite direktiivi 2004/22/EÜ rakendusmäärus“, AS Metrosert
Detsember 2005	Tabelarvutuse profikursus, BCS Koolitus
Detsember 2005	Seminar “Aktuaalsed küsimused metroloogias“, AS Metrosert
Oktoober 2005	Projekti juhtimine, Audentes Ariko

Teadustöö põhisuunad
Energia planeerimise modelleerimise ja mudelite uuringud, elektrisüsteemi arengu ja prognoosi modelleerimine.

DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *MECHANICAL AND INSTRUMENTAL ENGINEERING*

1. **Jakob Kübarsepp**. Steel-bonded hardmetals. 1992.
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3. **Mart Tamre**. Tribocharacteristics of journal bearings unlocated axis. 1995.
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5. **Jüri Pirso**. Titanium and chromium carbide based cermets. 1996.
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41. **Kristo Karjust**. Integrated product development and production technology of large composite plastic products. 2008.

42. **Mart Saarna**. Fatigue characteristics of PM steels. 2008.

43. **Eduard Kimmari**. Exothermically synthesized B_4C-Al composites for dry sliding. 2008.

44. **Indrek Abiline**. Calibration methods of coating thickness gauges. 2008.

45. **Tiit Hindreus**. Synergy-based approach to quality assurance. 2009.

46. **Karl Raba**. Uncertainty focused product improvement models. 2009.

47. **Riho Tarbe**. Abrasive impact wear: tester, wear and grindability studies. 2009.

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